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Economic Development Impact of Corridor Improvements

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16. Abstract

In recent years, the Indiana Department of Transportation (DOT) and other state transportation agencies have increasingly implemented non-capacity expansion projects or strategies due to their benefits in improving flow, safety, and reducing delay in the transportation network at low capital, operations, and maintenance cost. The quantification of the benefits of these strategies has also become very important due to increasingly challenging local and regional fiscal conditions. With this in mind, this project developed a framework and a tool for the evaluation of economic development impacts of corridor improvements at the sketch-level of planning. The resulting framework and tool, called “Tool for Operations – Economic Impact Analysis” (TOPS-EIA), is based on a framework and tool from the Federal Highway Administration (FHWA) called Tool for Operations Benefit Cost Analysis (TOPS-BC). TOPS-EIA takes the expected impacts of each strategy on corridor performance and translates them into business cost savings and economic development impacts through a set of statewide economic multipliers. TOPS-EIA is subdivided into 4 modules: arterial signal coordination (ASC) strategies, traffic incident management (TIM) strategies, work zone management (WZM) strategies, and access management (AM) strategies. Additionally, a qualitative tool for road diet (RD) strategies was developed. To demonstrate TOPS-EIA, two case studies of ASC strategies were conducted. The results showed that this type of strategies could provide not only significant user cost savings, but also economic development impacts, expressed as gross regional product, job-years, and real personal income. The proposed methodology and tool can assist DOTs, Metropolitan and Rural Planning Organizations (MPOs and RPOs) in assessing the benefits of non-capacity expansion projects at the early and middle stage planning processes and, therefore, contribute to better-informed decisions.

17. Key Words

non-capacity improvements, arterial signal coordination, traffic incident management, work zone management, access management, economic development impacts, sketch planning

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EXECUTIVE SUMMARY

PROJECT ECONOMIC DEVELOPMENT IMPACT OF CORRIDOR IMPROVEMENTS

INTRODUCTION

The Indiana Department of Transportation (INDOT) has undertaken a set of joint research efforts to gain a better understanding of the economic impacts that could arise from transportation investments, as well as to develop mechanisms to quantify them, especially during the early stages of the project development process. This study focuses on a set of corridor improvement projects that do not physically expand the capacity of corridors.

The primary objective of this research is twofold: (1) develop a theoretical framework where the effects of corridor improvements on the facility performance could be used to estimate a set of economic development indicators, and (2) develop a sketch-planning tool where the proposed framework is made operational.

THEORETICAL FRAMEWORK AND TOOL OVERVIEW

To develop the study framework, it was necessary to account for key differences between corridor improvements and traditional capacity expansion projects. Typically, corridor improvements involve shorter project lifetimes. Similarly, because the benefits are highly dependent on the type of technology implemented, they are not static, as the technology continually evolves. Finally, the expected impacts of their implementation are much smaller than those of capacity expansion projects.

Within this context, the adopted approach for evaluating the economic impacts of non-capacity transportation projects involved the following:

- estimating the impacts of the corridor improvement on key performance measures (such as mobility and safety) and corresponding user costs;
- estimating the portion of user costs that corresponds to business savings; then
- translating the accumulated business savings to economic development impacts through statewide economic multipliers.

Based on the theoretical framework, literature review findings, and existing tools for similar analyses, four tool development options were considered. The preferred option was a framework based on the Federal Highway Administration's (FHWA's) tool, Tool for Operations Benefit Cost Analysis (TOPS-BC). The resulting tool, called Tool for Operations—Economic Impact Analysis (TOPS-EIA), is briefly described in the following section.

TOPS-EIA Tool

TOPS-EIA is a tool that is applicable at the initial stages of the project development process, where various project alternatives or configurations can be examined with a low level of detail in the inputs and outputs. In that sense, TOPS-EIA calculates the economic savings in travel time, travel time reliability, vehicle operating costs, and safety by mode and trip purpose using a set of expected impacts taken from past studies and projects. Subsequently, the annual business savings corresponding to trucks and automobiles on business purpose are translated into economic development impacts using statewide economic multipliers.

The main inputs of the tool include the length of the period of analysis, the length of the segment, the number of lanes, and the volume of vehicles on the segment under analysis. Optional inputs include free-flow speed, link capacity, and strategy-related impacts on facility performance. The outputs of the tool include three types of economic impacts: gross regional product (GRP) in millions of dollars, personal income in millions of dollars, and employment in job-years.

TOPS-EIA is subdivided into four modules, with one module for each strategy. These strategies are arterial signal coordination (ASC) projects, traffic incident management (TIM) projects, work zone management (WZM) projects, and Access Management (AM) projects. A qualitative tool was developed for road diet (RD) strategies called the *RD case search tool.*

To demonstrate TOPS-EIA, two case studies involving arterial signal coordination strategies were conducted—one in Indiana and one outside Indiana. The case study in Indiana involved the implementation of a traffic-actuated system on a five-mile segment of SR 37 between I-69 and SR 32 in Hamilton County. The results of the ASC tool showed that this project brought not only significant user costs savings, but also economic development impacts expressed as GRP, employment, and real personal income.

IMPLEMENTATION

TOPS-EIA can be used for project selection, project prioritization, or multi-criteria analysis (MCA). Intermediate outputs of the tool, such as user benefits (e.g., travel time savings), can be used in benefit-cost analysis (BCA). The latter, however, will require the calculation of project costs, which is not available in TOPS-EIA. For MCA, different indicators such as GRP, personal income, employment, and other intermediate outputs generated by the tool can be incorporated directly as criteria in the decision-making process. The main advantage of MCA is its robustness with respect to double-counting or overlap of users' benefits. In this process, it should be taken into account that the economic development benefits measured by the tool are statewide impacts.

Further steps for the tool implementation, as part of this project, included a set of training sessions, webinars, and presentations provided for INDOT and Metropolitan Planning Organizations (MPOs). These sessions covered both the theoretical background and a case study to demonstrate the use of TOPS-EIA.

Tool Limitations and Future Research

While TOPS-EIA has the potential to measure the economic development impacts of a wide range of strategies, its simplicity and practicality brings a set of assumptions and limitations that are opportunities for future improvements. These include the following:

- The tool does not account for possible synergies among multiple strategies implemented on the same corridor.
- TOPS-EIA does not take into account either induced travel or consumer surplus.
- Although TOPS-EIA is able to account for nonrecurring congestion, a more detailed breakdown of nonrecurring congestion sorted by its causes can be added.
- The economic multipliers used in TOP-EIA reflect statewide impacts. Therefore, they are applied independently of the region where the project is located.
- Finally, the tool estimates the economic development impacts from savings in business travel costs as a result of the implementation of the nontraditional corridor improvements. Future research could explore additional economic benefits triggered by improvements on market accessibility or enhancements on intermodal connectivity.

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1. INTRODUCTION

1.1 Background

"Corridor improvements" refer to the implementation of features in a corridor in order to optimize its efficiency or performance. These improvements do not directly expand the capacity of the facility (as does adding lanes), but they could have a positive effect by addressing issues such as congestion and unreliable travel times. Corridor improvements could be grouped under a major class of measures and strategies called "Transportation Systems Management and Operations" (TSM&O). TSM&O are defined as "practices that optimize the performance of the transportation system by using advanced technologies and enhanced interagency coordination to better manage and operate roads, bridges, intersections, and other elements of the transportation system" (GTC, 2016). TSM&O has three main categories (FHWA, 2012):

1. Operations strategies: Operations strategies refer to the deployment of infrastructure that affects directly the movement and people of goods in the corridor. These types of measures are the main focus of the strategies described in this report.
2. Supporting infrastructure: Supporting infrastructure refers to the facilities required to enhance the functioning of roadside operations.
3. Nonphysical strategies: Non-physical strategies aim to improve the efficiency and effectiveness of the deployed systems by, for instance, fostering interagency coordination, system integration, or implementation of active transportation and demand management (ATDM) strategies (FHWA, 2012).

TSM&O strategies are intended to positively impact the performance of the facility and, therefore, the user costs of the people and businesses using the facility. The quantification of these benefits are very important due to increasing competitive local and regional fiscal conditions, in which the benefits of TSM&O strategies are compared to the benefits of more traditional highway improvements. Previous efforts such as the Tool for Operations Benefit Cost Analysis (TOPS-BC) (FHWA, 2012) and Traffic Incident Management Benefit-Cost (TIM-BC) Tool (FHWA, 2015), enabled the analysis of traditional user benefits of TSM&O strategies; however, none of these tools can perform an evaluation of their economic development impacts. This evaluation constitutes the main objective of this project.

Economic development is a result of business activity expansion in a region. It is designed to improve the quality of life in an area by increasing income, job choices, activity choices, stability, and amenities (Forkenbrock & Weisbrod, 2001). The U.S. Congress stresses the need for assessing the economic development impacts of transportation investments through different legislation. For example, the National Environment Policy Act (NEPA) of 1969 required all Federal agencies to select projects using the approach that incorporates social, economic, and natural environment factors (Gkritza, 2006). Transportation bills such as the Transportation Equity Act for the 21st Century (TEA-21) in 1998, Moving Ahead for Progress in the 21st Century Act (MAP-21) in 2012, and Fixing America's Surface Transportation (FAST) Act in 2015 all manifest again the interest of the U.S. government in having the economic development impacts of projects assessed.

To date, economic development impacts have been a common criterion in the project ranking process of many State Departments of Transportation (DOTs) and Metropolitan Planning Originations (MPOs). Considering the popularity of TSM&O strategies, there is a foreseeable increase in the need to assess their impacts on a region's economic development.

The objectives of this project were two twofold. First, investigate the synergies among travel demand, traffic, and economic impact models in evaluating alternative corridor-level projects. Second, investigate ways to adapt the existing tools measuring the economic benefits of TSM&O strategies and develop a post-processing method to meet the needs of INDOT's Division of Asset Planning and Management.

The deliverables of this study will be used by INDOT for middle-stage transportation planning involving single projects and/or for transportation programming. To this end, three specific tasks were undertaken:

1. Overview of the available tools and method to measure the economic impacts of corridor improvements.
2. Development of a framework to adapt an existing tool to measure economic development impacts of a set of TSM&O strategies suggested by INDOT.
3. Development of a tool with simple interface that builds upon another tool called TOPS-BC.

The information provided herein aims to provide the following benefits for INDOT:

- Offer guidance to INDOT about evaluating the economic impacts of corridor improvements.
- Provide information to support the decision-making process when evaluating projects at the middle-stage transportation planning or transportation programming, or the early stages of project development.
- Assist INDOT with communicating with elected officials, the general public, and stakeholders.

1.2 Organization of the Report

The structure of this report is as follows. Chapter 2 presents an overview of the economic development impacts associated with corridor improvements. This chapter also presents and overview of available tools to measure the economic benefits of corridor improvements. Chapter 3 provides the description of four different framework options to evaluate the economic development impacts of non-capacity corridor improvements, as well as a description of the chosen tool development framework. Chapter 4 presents a description of the tool developed as well as discussion of its main inputs and outputs. Chapter 5 demonstrates the application of the tool in two case studies, one in

Florida and the other in Indiana. Finally, a summary of the key findings, lessons learned and opportunities for future research are presented in Chapter 6.

2. REVIEW OF KEY CONCEPTS AND TOOLS USED IN THE ECONOMIC ANALYSIS OF OPERATIONAL STRATEGIES

This chapter describes the key concepts involved in this project, including economic efficiency, economic development impacts, and wider economic impacts of transportation projects. The definition of non-traditional corridor improvements is also provided. Next, tools for the measurements of economic efficiency and economic development impacts as well as past related studies are summarized. Finally, impacts of nontraditional corridor improvements are discussed.

2.1 Basic Concepts

2.1.1 Economic Development and Transportation Systems

Economic efficiency, economic development impacts, and wider economic benefits are common concepts in the evaluation of the economic value of a transportation system. Each has its own unique performance measures to capture the distinct attributes of economic value from a transportation investment. For instance, economic efficiency is used for estimating the dollar value of benefits obtained from a transportation investment. Economic development impacts, on the other hand, are used to explain the predicted overall impacts of a transportation investment on the local economy using indicators like employment, Gross Regional Product (GRP), and income.

2.1.2 Economic Efficiency

Economic efficiency usually refers to the monetary value of costs and benefits generated by transportation infrastructure investment (Sinha & Labi, 2007). A cost-benefit analysis is one way to evaluate the economic efficiency of a set of alternatives. Typically, a “no-build case” is compared to one or more alternatives featuring different improvements in order to compare the incremental differences between the base case and the alternative(s) (MnDOT, 2015).

Benefit-Cost Ratio (BCR) is a good proxy for benefit-cost analysis. The BCR is the ratio of monetary value of highway standard user benefits (i.e., travel time savings, vehicle operating savings, and safety savings) and non-user benefits (i.e., air quality improvements or water quality improvements) from a transportation infrastructure investment to the costs (i.e., capital cost, maintenance and operation costs) incurred during the analysis period (Sinha & Labi, 2007). A BCR value greater than 1.0 indicates that the investment is economically feasible.

2.1.2 Economic Development Impacts

Economic development seeks to improve a community’s economy by increasing employment, income, productivity, property values, and tax revenues. Economic development impact types can be summarized into two groups (Sinha & Labi, 2011):

- Impact types related to the regional economy, such as economic output, personal income, and employment.
- Impact types related to a particular aspect of economic development, such as productivity, capital investment, and tax revenues.

Economic development impacts can be closely related to one another. It is common that an economic development change is reflected by two or three types of economic development impacts (Sinha & Labi, 2011). The economic development impacts of transportation projects can be further placed into four groups of categories: direct impacts, indirect impacts, induced impacts, and dynamic impacts. An expanded definition for each of these impacts is given in Forkenbrock and Weisbrod (2001). Figure 2.1 illustrates these categories of economic development impacts.

2.1.2.1 Direct Economic Impacts. Cost savings resulting from changes in transportation system characteristics (such as travel time and safety) and changes in costs (such as vehicle operating costs) can enhance business output and increase productivity in a region, thus making a region more competitive. Direct business activity outputs are considered as direct economic impacts. For example, reduced transportation costs to reach a grocery store can attract more customers and generate more business for the store.

2.1.2.2 Indirect Economic Impacts. Indirect impacts from a transportation investment refer to the benefits to suppliers from changes in business output. For instance, a new highway improves the mobility of a freight company (increasing the business output of the company) in that corridor. The improvement enables the freight company to offer better service to markets. The employees of the freight company may also benefit by increased wages.

2.1.2.3 Induced Economic Impacts. Induced economic impacts happen when the people in a region spend more money on buying higher quality goods and services than before, because of their increased income.

2.1.2.4 Dynamic Economic Impacts. Dynamic economic impacts represent changes in business locations, land value and environmental conditions in the long run.

2.1.3 Wider Economic Impacts

Wider economic impacts of transportation projects mainly concern the impacts on business productivity, which captures efficiency gains from business-related

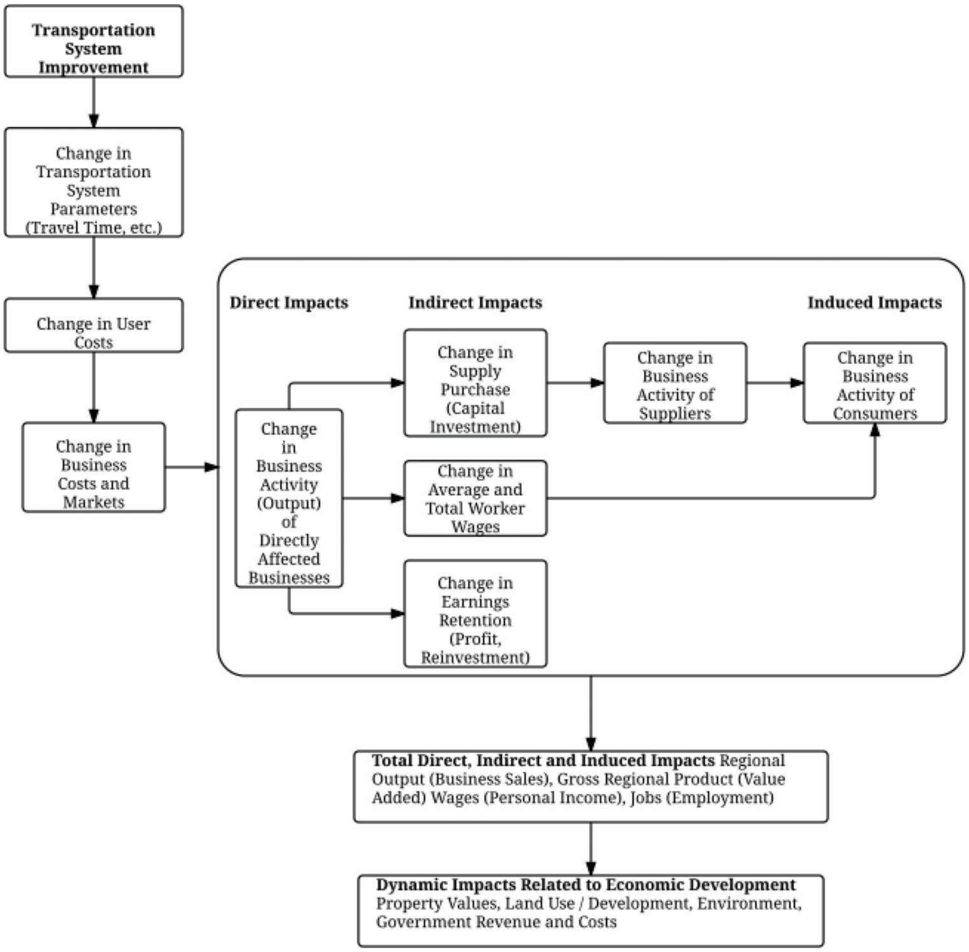


Figure 2.1 Categories of economic development impacts. (Source: Weisbrod, 2000.)

travel. Adjustments in a region's reliability of movements, accessibility to markets, and connectivity to intermodal facilities are major elements involved in wider economic impacts (NCHRP, 2014).

2.1.3.1 Reliability. Reliability benefits accrue when the duration of traffic incidents is reduced, especially under congested scenarios. The enhancement of travel time reliability provides better assurance for on-time performance of freight pick-up and drop-off services as well as for employees' punctuality at their places of work (SHRP2, 2014).

2.1.3.2 Market Access. Market access could be defined as the degree of ease with which a business can access customers, suppliers, and labor markets from a given location. Some transportation projects could have significant effects on market access by, for example, enlarging the number of destinations that can be served from a single business location (SHRP2, 2014).

Market access can be further broke down to *access to buyer-supplier markets* and *access to labor markets*. *Access to buyer-supplier markets* focuses on measuring economies of scale triggered by the expansion of the customer delivery market served from a certain business site and the expansion of supplier locations that can deliver to that business site in a day due to a highway transportation improvement in the region. *Access to labor markets* focuses on measuring economies of scale trigged by the expansion of the labor market due to a transportation project. The transportation-induced economies of scale occur through the better connection between specific business needs and worker proficiencies, as well as the better exchange of information among skilled labor (knowledge spillovers).

2.1.3.3 Intermodal Connectivity. Intermodal connectivity aims to reduce overall travel time from business locations to intermodal terminals (like airports, marine ports, rail terminals, and intermodal truck- rail facilities) (SHRP2, 2014).

2.2 Definition of Nontraditional Corridor Improvements

Nontraditional corridor improvements refer to strategies that may have nontraditional design features and/or objectives. Traditional improvements mainly include capacity improvements. Nontraditional improvements, on the other hand, focus on improving mobility and safety of traffic through technologies (i.e., intelligent transportation system strategies) or minor treatments (e.g., road diets). The definition of the nontraditional corridor improvements that re considered in this project are as follows:

Arterial Signal Coordination: This strategy involves the coordination of traffic signal timing patterns and algorithms to smooth traffic flows—reducing stops and delays and improving travel times. This strategy can be implemented on a small corridor, a limited grid, or region wide in aggressive deployments. The sophistication of the timing coordination can also vary from simple preset timing programs to more advanced traffic actuated corridor system, to fully centrally controlled applications (FHWA, 2012).

Traffic Incident Management (TIM): This set of strategies often includes several sub strategies that may be combined to create a coordinated system. The benefits of these TIM systems include a reduction in incident related delay (and associated fuel use and emission impacts), and can include safety benefits by allowing for the faster dispatch and response of emergency personnel and assets to injury crashes. The TIM strategies include the following (FHWA, 2012):

a. *Incident Detection and Verification*—Involves the implementation of surveillance, detection, communications, and algorithms to enhance the monitoring of the transportation system to more quickly detect the occurrence of incidents and provide more information to system operators to verify the location and severity of the incident, so that an appropriate response plan may be developed and implemented.
b. *Incident Response*—Involves the improved development, communication, and implementation of response plans through coordinated response strategies and computer—aided dispatch (CAD) systems.
c. *Freeway Service Patrols (FSP)*—Involves prepositioned or roving "highway helper" vehicles designed to quickly respond to system incidents and mitigate the situation. These vehicles may also provide first responder capabilities for more serious crashes or incidents until more appropriate emergency assets and personal arrive on scene.

Work Zone Management: Involves the coordinated implementation and use of pretrip (e.g., 511-web-based applications) and in-route (e.g., dynamic message signs and highway advisory radio) traveler information, along with construction traffic management and alternative construction work hours planning to mitigate the congestion related to construction work zones (FHWA, 2012).

Access Management: The Federal Highway Administration defines access management as "the proactive management of vehicular access points to land parcels adjacent to all manner of roadways." According to this definition, the major techniques involved in access management include access spacing, driveway spacing, safe turning lanes, median treatments, and right-of-way management (FHWA, 2015).

Road Diets: Road diet typically pertains to the technique of converting four-lane undivided roadway segments into three-lane segments with two through lanes and a centered two-way left-turn lane (FHWA, 2015).

2.3 Tools for Measuring Economic Efficiency

Previous research from federal, state, and regional transportation agencies has identified many methodologies and tools designed to evaluate the projects that utilize Nontraditional corridor improvements. These methodologies and tools range from conducting onetime, simple analysis to performing a more complex benefit-cost analysis within a structured framework.

Table 2.1 includes the most commonly used tools for economic efficiency evaluation (FHWA, 2012; Jiang, Zhao, & Li, 2013). Table 2.2 provides a comparison of these tools by type of analysis and operation strategy. These include:

- Net, Highway Benefit–Cost Analysis System, is a web-based benefit-cost tool developed by FHWA. CAL-B/C, California Life-Cycle Benefit/Cost Analysis Model, is an Excel spreadsheet-based tool developed by Caltrans.
- COMMUTER model, a spreadsheet-based tool developed by the U.S. EPA (U.S. Environment Protection Agency).
- EMFITS, the Evaluation Model for Freeway ITS Scoping, a methodology developed by New York State Department of Transportation.
- FITSEval, the Florida ITS Evaluation tool, is software developed by the Florida Department of Transportation.
- HERS-ST, Highway Economic Requirements System State Version, is a software developed by the FHWA. IDAS, ITS Deployment Analysis System, is another a software developed by FHWA to help federal and state agencies to develop highway investment programs and policies that maximize economic benefits relative to costs.
- IMPACTS, is a series of spreadsheets related to the STEAM model. SCRITS, Screen Tool for ITS, is a spreadsheet-based tool developed by FHWA. STEAM, Surface Transportation Efficiency Analysis Model is a software using information developed through the travel demand modeling process to compute the net benefits of mobility and safety, developed by the FHWA.
- TOPS-BC, the Tool for Operations Benefit/Cost, was developed by the FHWA to:
    1. allow users check the expected range of nontraditional corridor improvement impacts based on a database of observed impacts in other areas;
    2. provide users guidance to identify appropriate B/C methods and tools according to the input needs of their analysis;
    3. provide users the ability to estimate life-cycle costs of a wide range of nontraditional corridor improvements; and
    4. allow users to estimate benefits using a spreadsheet-based sketch planning approach and compare it to the estimated strategy costs (FHWA, 2012). Performance measures covered in TOPS-BC include travel time, travel time reliability, energy and safety. With a number of default parameters developed by past research data, TOPS-BC provides users flexibility to either use default parameters or overwrite them with local data.

- TRIMMS, Trip Reduction Impacts of Mobility Management Strategies, a visual basic (VB) application spreadsheet model developed by the National Center for Transit Research and the Center for Urban Transportation

TABLE 2.1
General Comparison of Tools for Economic Efficiency Evaluation

Name	Developed By	Tool Version	Application Stage	Geographic Scope of the Analysis	Stand-alone Application	Cost
BCA. Net	FHWA	Web-based	N/A	Project, Corridor Level	Yes	Free
CAL-B/C	Caltrans	Spreadsheet	N/A	Project, Corridor Level	Yes	Free
COMMUT-ER	US EPA	Spreadsheet	N/A	N/A	Yes	N/A
EMFITS	NYSDOT	Methodology	N/A	Project, Corridor Level	Yes	N/A
FITSEval	FDOT	Software	Sketch Planning	Regional, Corridor Level	TDM Post-processor	Free
HERS-ST	FHWA	Software	N/A	Statewide Level	Yes	Free
IDAS	FHWA	Software	Sketch Planning	Project, Corridor, Regional, Statewide, Level	TDM Post-processor	Requires License Fee
IMPACTS	FHWA	Spreadsheet	N/A	Corridor, National Level	Related to STEAM Model	N/A
SCRITS	FHWA	Spreadsheet	Sketch Planning	Project, Corridor Level	Yes	N/A
STEAM	FHWA	Software	N/A	Project, TAZ, Districts, Regional Level	Yes	Free
TOPS-BC	FHWA	Spreadsheet	Sketch Planning	Project, Corridor Level	Yes	Free
TIM-BC	FHWA	Spreadsheet	Sketch Planning	N/A	Yes	Free
TRIMMS	CUTR of USF	Spreadsheet	N/A	Census, Regional, National Level	Yes	Free
Redbook Wizard	AASHTO	Spreadsheet	N/A	Project, Corridor Level	Yes	Free
MicroBENCOST	TTI	DOS-based	N/A	Project, Corridor Level	Yes	Requires License Fee

Research at the University of South Florida. Redbook Wizard is an interactive excel spreadsheets-based tool developed by the FHWA to help carry out benefit-costs analysis for highway projects. MicroBENCOST, was developed in the early 1990's through the National Cooperative Highway Research Program as a framework for benefit-cost analysis of highway projects on a personal computer.

- TIM-BC (Traffic Incident Management Benefit-Cost) is a scenario-planning tool developed to measure the economic benefits associated with a group of traffic incident management strategies. The strategies include highway safety service patrols, driver removal laws, authority removal laws, shared quick-clearance goals, pre-established towing service agreements, dispatch collocation, TIM task-forces, and SHRP2 training. The tool combines table of impacts with regression equations (hybrid statistical-simulation methodology) for travel delay, fuel consumption, and other parameters to perform a benefits cost analysis of each strategy.

It can be seen that, first, these tools vary in design features and aim to analyze different types of projects. For instance, HERS-ST is mainly designed for capacity improvement projects, and only contains a few selected Nontraditional corridor improvements. Additionally, tools developed by state agencies, such as EMFITS, FITSEval Tool, or MicroBENCOST, can be a good fit for a state's particular needs, but the application of the tool at the national level may be inappropriate. CAL-BC was not developed with national data; therefore, the default values embedded in the tool are questionable for adoption in a national application. In this sense, TOPS-BC and IDAS are two tools that emphasize economic efficiency assessment of a wide range of TSM&O or Intelligent Transportation System (ITS) strategies; both also have applicability at the national level.

2.4 Tools for Measuring Economic Development Impacts

Economic multipliers or economic models (input output, econometric, and computable general equilibrium) are used for converting the economic benefits into relevant economic impacts. Regional value added, employment, and income are commonly used performance measures of impact on economic development. Up to this point, efforts to develop tools for the economic analysis of transportation projects have been led by State Departments of Transportation (DOTs) as well as individual firms; for example, the Economic Development Research Group (EDRG). At the national level, a series of tools have been developed to assess the economic value of transportation projects at different stages in the planning process with varying objectives and data requirements.

TABLE 2.2
Comparison of Tools in Terms of Analysis Types and Operational Strategies

Tool	Analysis Type	Operational Strategy Type
BCA. Net	Benefit-Cost Analysis	Intersection Improvements
CAL-B/C	Benefit-Cost Analysis, Lifecycle Benefits, Net Present Value, Rate of Return on Investment, and Payback Period	Highway Operational Improvements, Transportation System Management strategies, and ITS strategies
COMMUTER	Benefit-Cost Analysis	Employer-based Transportation Demand Management strategies
EMFITS	Benefit-Cost Analysis	ITS strategies
FITSEval	Benefit-Cost Analysis	ITS strategies from the state's standardized FSUTMS model structure
HERS-ST	Benefit-Cost Analysis, Cost Estimates, and System Condition Prediction	Highway Operational Improvements
IDAS	Benefit-Cost Analysis, ITS Deployment Alternatives Comparison, Impacts and Traveler Responses to ITS, Develops Inventories of ITS Equipment Needed for Proposed Deployments, Identifies Cost Sharing Opportunities, and Life-cycle Costs (Including Capital and O&M Costs for the Public and Private Sectors)	ITS strategies
IMPACTS	Benefit-Cost Analysis, and Screening-Level Evaluation of Multimodal Corridor Alternatives	HOV lanes, Conversion of an Existing Highway Facility to a Toll Facility, and Employer-based Travel Demand Management strategies
SCRITS	Benefit-Cost Analysis	User benefits of ITS strategies, can be viewed as a subset of TOPS-BC
STEAM	Benefit-Cost Analysis of Mobility and Safety, Congestion Impacts, CO2 and Greenhouse Gas Emissions, Access to Jobs, Revenue and Transfer Revenue, and Level of Risk in Estimated Results	Transportation Demand Management strategies
TOPS-BC	Benefit-Cost Analysis, Potential Impact of Strategies, Research Available Analysis Methods and Tools, and Life-cycle Costs	Transportation System Management and Operations (TSM&O) strategies
TIM-BC	Benefit-Cost Analysis	Traffic Incident Management (TIM) strategies
TRIMMS	Benefit-Cost Analysis, Adverse Global Climate Change Impacts, and Cost-Effectiveness	Transportation Demand Management strategies
Redbook Wizard	Benefit-Cost Analysis, User Benefits from Operation, User Benefits from Construction, Total User benefits, Net User Benefits, Total Operation Delay, Total Construction delay, and Total VMT Benefits	Signal Control Systems, ITS strategies, and Intersection Improvements
MicroBENCOST	Benefit-Cost Analysis, Net Present Value, Internal Rate of Return, Change in Emissions of Carbon Monoxide, and Change in Fuel Consumption	Intersection/Interchange Improvements and HOV projects

Figure 2.2 shows the existing tools for the assessment of social and economic effects of transportation projects, built upon the various methods offered in NCHRP 456 (Forkenbrock & Weisbrod, 2001). The main contribution of the flowchart is to provide theoretical guidance to transportation professionals when they assess the economic development impacts of Nontraditional corridor improvements. Beyond the categorization of the tools, this report examines the advantages and drawbacks of economic multipliers (input-output tables) and dynamic economic models (economic forecasting and simulation models) that can be utilized in the evaluation process of Nontraditional corridor improvements. Comparisons of varying input-output tables and dynamic economic models are also presented.

2.4.1 Input-Output Models

Input-output models measure economic impact by inputting the direct impacts into the model and deriving the indirect and induced impacts as outputs. For one industry, the input-output models estimate how many units of input this industry requires from all industries to generate a unit of output within a certain range.

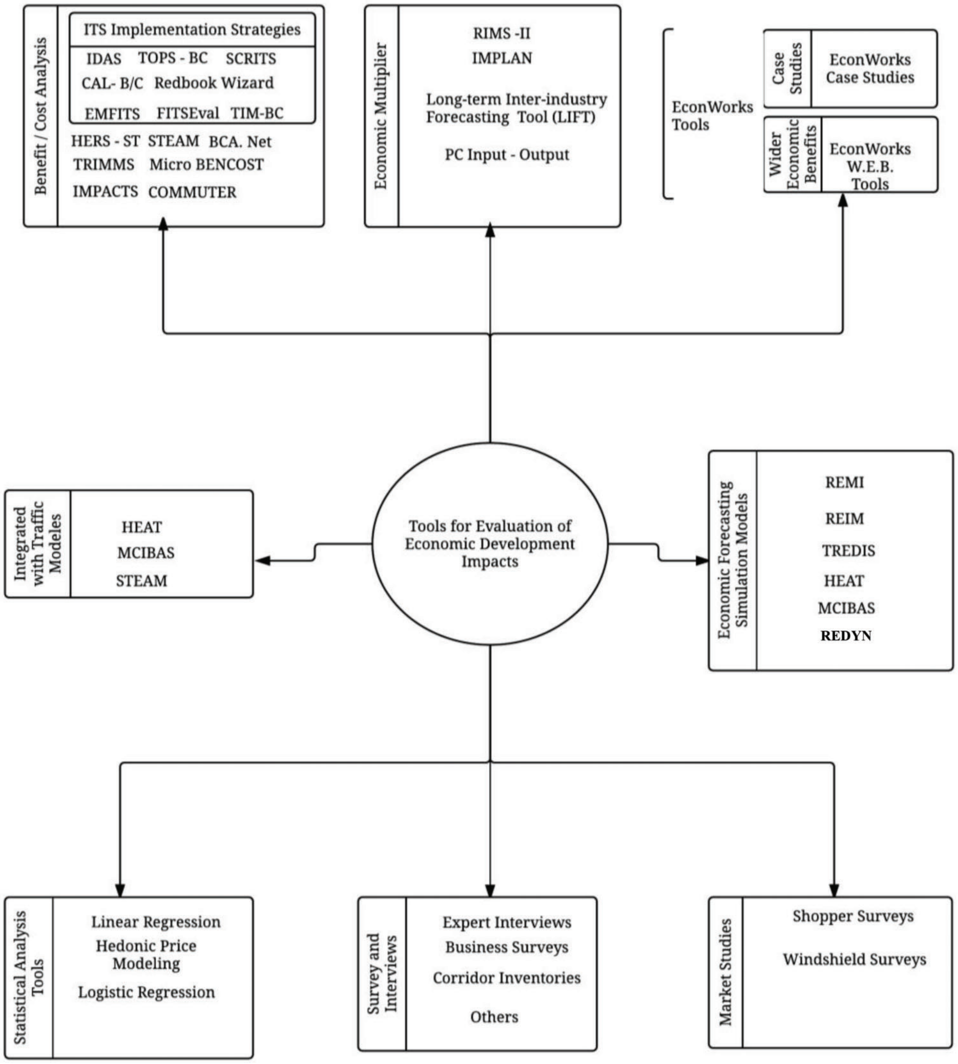


Figure 2.2 Existing tools for the evaluation of transportation projects.

Impact Analysis for Planning (IMPLAN) and Regional Input-Output Modeling System (RIMS-II) are widely used input-output models (Xiong, Fricker, McNamara, & Longley, 2012). The Long-Term Inter-Industry Forecasting Tool (LIFT) is another useful input-output model designed for the dynamic macroeconomic modeling of industry in the U.S (Inforum, n.d.).

2.4.1.1 Advantages of Input-Output Models. Wide adoption of economic development analysis at the national level is one advantage of input-output models. Beyond capturing the direct, indirect, and induced impacts of purchasing goods and services within the study region (Perlich, 2014), input-output models can also capture inter-industry outputs within industry sectors (Litman, 2009).

2.4.1.2 Limitations of Input-Output Models. Input-output models usually require a large data matrix input, which may not be appropriate for the economic development impact evaluation of a small area. Performing the input-output models can be costly because they often require users to find ways of acquiring available data for a particular situation. Input-output models can result in an over-estimation of a future job's creation. This is because most are static and they estimate indirect and induced impacts by analyzing backward factors such as domestic inputs and productivity (Litman, 2009). Furthermore, input-output models only evaluate the primary and partial secondary economic impacts of a transportation project (Xiong et al., 2012). Finally, when a newly added industry sector enters the study region, the input-output table is incapable of automatically updating its relation with other involved industry sectors (Perlich, 2014).

2.4.1.3 Comparison of IMPLAN and RIMS II. The comparison of IMPLAN and RIMS II is conducted herein on the basis of different criteria. First, RIMS II is a spreadsheet-based input-output model built upon data from the US Bureau of Economic Analysis's (BEA) national I-O Table and Regional Economic Accounts

(BEA, 2015). IMPLAN was developed both in a website-based version IMPLAN Online, and a PC-based version, IMPLAN Pro. The primary data sources used to build IMPLAN were the U.S. Bureau of Labor Statistics (BLS), U.S. Bureau of Economic Analysis (BEA), U.S. Census Bureau County Business Patterns (CBP), and U.S. Department of Agriculture Census (IMPLAN, n.d.).

Additionally, for the industry sector scheme, RIMS II incorporates RIMS II incorporates 369 detailed industries and 64 industry aggregate. IMPLAN, on the other hand, contains 538 disaggregated industry sectors. However, IMPLAN sectors are unique because of commodity by industry IO approach. For the aggregated industry sectors, IMPLAN allows users to customize the list according to their needs (Lynch, 2000). In terms of multipliers, RIMS II multipliers can be compared by state, since they were established by a nationwide estimating process (Gkritza, 2006).

Similarly, for IMPLAN, since users must import expenditure data and specify the timespan, they need to adjust the monetary value of the expenditure data to be consistent with the imported years as well (Gkritza, 2006). Researchers found that highway construction disbursements impact industry sectors in the national I-O matrix, including Construction, Real Estate, and Architectural and Engineering Services (Lynch, 2000). For these sectors, IMPLAN allots higher values of income multipliers than RIMS II, but lower values for output multipliers and employment multipliers (Gkritza, 2006).

It is worth mentioning that the spreadsheet-based tool I-RIMS Multipliers, developed by IMPLAN, is most similar to RIMS II in IMPLAN products. Compared to RISM II, I-RIMS contains more updated data and produces faster results. In addition, as mentioned previously, the most recent version of RIMS II incorporates 406 disaggregated industry sectors and 62 aggregated industry sectors (BEA, 2015). Users of I-RIMS can choose to buy multipliers from the region package and the industry package. For either package, 460 industry sectors are equipped with data from 2011 and 2012, and 536 industry sectors are prepared with data from 2013. Table 2.3 shows a detailed comparison of IMPLAN (from both PC-based and online-based versions), I-RIMS, and RIMS II.

Specialty focus and retail margins are two unique criteria only met by IMPLAN Online and IMPLAN Pro. Specialty focus refers to special I-O industries and commodities contained in IMPLAN products but not included in the Standard Industrial Classification (SIC) or National American Industry Classification System (NAICS). Retail margins are the markup to the price of a product when a product is sold through a retail trade activity (BEA, 2016).

Table A.1 in Appendix A summarizes case studies with applications of IMPLAN and RIMS II at the state level. Finally, it should be noticed that IMPLAN is a multiregional IO or multicounty IO model (MRIO), where users can create regions by combining counties. RIMS II-MRIO can be requested from the U.S. Bureau of Economic Analysis (BEA).

TABLE 2.3
Comparison of I-RMIS, RIMS II, IMPLAN Online and IMPLAN Pro

Criteria	**I-RIMS**	**RIMS II**	**IMPLAN Online**	**IMPLAN Pro**
General Broad-Spectrum Usage	Yes	Yes	Yes	Yes
Specialty Focus	No	No	Yes	Yes
Edit Underlying Data & Assumptions	No	No	Yes	Yes
Retail Margins	No	No	Yes	Yes
Time Series Data	No	No	No	No
Consultant Service	No	No	No	No
Visualization Tools	No	No	No	No
Product Types	Spreadsheet/PDF	Spreadsheet/Software	Software & Data	Software & Data
Cost	$	$	$$	$$
Time to Receive	Same day	1–10 business days	Most data instantly download	Same day
Trade Method	Trade Flows	Location Quotient	Trade flows/eRPC/SD/Pooling	Trade flows/eRPC/SD/Pooling
Elasticities	None	None	Fixed price model	Fixed price model-customizable
Forecasting	No	No	No	No
Multiplier Types	Final Demand	Final Demand	Type I & SAM	Type I & SAM
Economic Impact Analysis	Yes	Yes	Yes	Yes
Output*	Yes	Yes	Yes	Yes
Employment*	Yes	Yes	Yes	Yes
Income*	Yes	Yes	Yes	Yes

*These are general performance measures provided by economic impact analysis. Source: IMPLAN (n.d.) and Lynch (2000).

2.4.2 Dynamic Economic Models

In contrast to input-output models, dynamic economic models are forecasting models that provide a more complex and comprehensive evaluation of a transportation investment's impact on economic development, including long-term impact estimation. TREDIS and REMI are two widely used tools with a variety of applications.

2.4.2.1 TREDIS. TREDIS is a web-based Transportation Economic Development Impact System that measures the economic output of transportation projects at the project development stage of the transportation planning process. Designed to help transportation planners conduct multiple economic-related analyses of transportation projects, TREDIS can evaluate the economic impacts and benefit-cost of a single transportation investment as well as assess the fiscal and public–private financial impacts of a set of project alternatives (EDRG, 2014c). Table B.1 in Appendix B shows all the features included in TREDIS version 4.0. Table B.2 in Appendix B provides the TREDIS 4.0 User Guidance—Single Project Flow Chart.

2.4.2.1.1 Advantages of TREDIS. Comprehensiveness and flexibility are two key features of TREDIS. Comprehensiveness is represented by the coverage of transportation modes, scope of projects, and the isolation of trip purpose. Coverage of all major transportation modes (car, bus, truck, train, aircraft, ship, and bike) enables TREDIS to analyze transportation projects, not only related to highway travel, but also to rail, aviation, marine, and pedestrian movement.

With respect to the scope of transportation projects, TREDIS is capable of both investigating the economic value of a highway corridor across several states and studying the economic efficiency of a single contraflow lane covering a few miles.

Combining different trip purposes with transportation modes enables TREDIS to perform economic analysis of a transportation project at different levels of traffic data detail. Users can choose to analyze a project through a rough estimation by only considering passenger cars (no split) and trucks (all trip purpose) or through a more exhaustive estimation, by taking account of passenger cars (combined with a split trip purpose like business, person, or commute) and trucks (all trip purpose). The transportation mode and trip purpose matrix determines the level of traffic data detail required for the TREDIS Travel Characteristic Model, shaping the accuracy of the analysis results accordingly.

Flexibility is exhibited by the compatibility and diversity of TREDIS. In terms of compatibility, TREDIS can theoretically work with any software package to generate the required traffic data input. TREDIS has been used with a variety of travel models and data sources, such as TransCAD, HERS, and IMPLAN. TREDIS' mode and trip purpose matrices provide users with various options for combining mode and trip purpose.

Moreover, the Market Access Module inside TREDIS focuses on capturing the improvements of business production, labor productivity, and international exports in a study region by measuring access to labor, industrial suppliers and customers, intermodal facilities with domestic services, and international gateway facilities. In other words, the Market Access Module gives TREDIS advantages to capture the wider economic benefits of that may result from implementation a group of nontraditional corridor improvements. This advantage can be explained by objectives of the Market Access Module. First, it aims to measure the improved business productivity, which is a reflection of greater accessibility to buyer-supplier markets. Second, it aims to estimate the improved labor productivity induced by knowledge spillovers or labor skill matching, which is a proxy of better accessibility to labor markets. Third, it aims to assess the improved ability of intermodal exports, which represents the enhanced intermodal connectivity (EDRG, 2014b).

Population that can be reached within a 40-minute drive and employment that can be covered within a 3-hour drive are two factors involved to measure market accessibility. The market access benefits for the labor market access are characterized by measuring the size of local markets that can be reached on a one-way trip from the weighted centroid of population of a county within a 40-minute drive. 40 minutes driving time is commonly regarded as an average travel time for commute trips in the U.S.

The market access benefits for domestic industry supply chains are calculated by measuring total employment that can be accessed within a 180-minute drive from the center of weighted population of a county in U.S. The 3-hour driving time represents the estimated travel time for trips and reflects the market access benefits in terms of domestic supply chains because it is an appropriate approximation for "same-day deliveries," according to industry surveys (Alstadt, Weisbrod, & Cutler, 2012). These thresholds are calculated by a gravity model that describes both the zonal market size (population or employment centered) and zonal access time (functions as a decay factor). Furthermore, it is noted in the TREDIS user manual that employment can denote the access of considered industries better than the population with respect to regional business activities (EDRG, 2014b, 2014c).

2.4.2.1.2 Limitations of TREDIS. TREDIS estimates reliability based on the Buffer Time Index (BTI), which describes the overall relationship between the percentage of congested vehicle-miles-traveled (VMT) and the percentage of additional time that should be budgeted to ensure on-time arrival. Buffer Time is one of the approaches that account for nonrecurring congestion. The FHWA prescribes the calculation of buffer time index. Basically, this index shows the relationship of 95th percentile travel rate, average travel time rate, and weighted VMT (vehicle miles traveled) for all study sections (Cambridge Systematics, Inc., 2008).

The appropriate volume and capacity relationship is required as input for the buffer time index as well.

TREDIS requires users to input the travel time (or speed) changes due to the application of the project or strategy as well congestion levels of chosen combination of trip purpose and transportation mode (e.g., passenger cars of business trip) to calculate the travel time benefits and travel time reliability benefits. This requirement is hard to be met by users who cannot obtain the related information from a travel demand model.

A second limitation is found in its "linked area" feature. This feature does not have an explicit impact on the resulting estimates for a study area with a large market and diverse economic base. Although the "linked area" was defined as "the external region(s) that are directly connected to, but not within, the study regions" (TREDIS v4.0 User Manual, p. 18, EDRG, 2014c), the linked area actually only influences the analysis results in the scenario where the study area is not yet economically vibrant but able to grow if it connects to an external area with a robust economy (TREDIS, n.d.).

Furthermore, TREDIS does not offer users options to customize the list of industry sectors. TREDIS employs CRIO-IMPLAN, a dynamic input-output model that "combines an interregional I-O model with trade flows, together with a time series framework for estimating economic growth forecasts over time" (NCFRP, 2011). The industry sectors embedded in CRIO-IMPLAN are fixed for each county and imported to the Economic Adjustment Module in TREDIS at the beginning of the analysis, so users can view the business productivity results for a list of affected industry sectors aggregated by TREDIS, rather than selecting sectors they are interested in.

Finally, TREDIS is not a free tool. The default values inside TREDIS were obtained through numerous data sources and methods. The licensing cost of TREDIS reflects these features. Table A.3 in Appendix A features the case studies with applications of TREDIS at the state level.

2.4.2.2 REMI Policy Insight. REMI Policy Insight is a dynamic forecasting model that investigates the effects of policy on regional economy and demography. In the 1970s, Treyz and others (who established Regional Economic Models, Inc. (REMI)) developed the Massachusetts Economic Policy Analysis (MEPA). MEPA is expanded and generalized under a grant from the National Cooperative Highway Research Program (NCHRP) and establishes the basis for REMI's models (Treyz, 1996). REMI includes four major modeling approaches: input-output, computable general equilibrium models, economic, and new economic geography, to capture inter-industry, long-term economic, demographic, and spatial dimension changes in the study region over the analysis period.

There are five basic blocks make up the structure of REMI (n.d.a):

1. *Output:* The output block contains output, demand, consumption, investment, government spending, exports, imports, and changes in output caused by changes in the productivity of the intermediate inputs.
2. *Labor and capital demands:* The labor and capital demand block consists of labor intensity, productivity, and demand for labor and capital.
3. *Population and labor supply:* The population and labor block deals with the labor force participation rate and migration equations.
4. *Wages, prices, and profits:* The wages, prices, and profits block incorporates composite prices, determinants of production costs, the consumption price deflator, housing prices, and wage equations.
5. *Market shares:* The market share block is designed for estimating the interactions of local, interregional, and export markets in each region.

2.4.2.1.1 Advantages of REMI. According to the developers of REMI, "98% of best practice REMI modeling is associated with research and developing high quality data inputs and model specifications"; as such, high quality input data is the principle strength of REMI (n.d.a). Second, multiple feedback loops from dynamic general equilibrium models guarantee credible forecasting results (AKRF, Inc., 2013). Third, REMI provides forecasts that take into account the time dimension, demographic detail, and behavioral econometric responses. Similar to TREDIS, REMI is capable of counting buyer-supplier market access benefits and labor market access benefits in its New Economic Geography Module.

2.4.2.1.2 Limitations of REMI. REMI is costly compared to other economic simulation models. In addition, REMI is complicated to use and may require an expert familiar with each model's application in order to conduct a reliable analysis (Gonin et al., 2015). It is challenging for users to understand the modeling process and the underlying assumptions of REMI because of the complexity of the model (AKRF, Inc., 2013). Table A.3 features case studies with REMI applications at the state level.

2.4.2.3 MCIBAS. MCIBAS was originally developed for the Indiana Department of Transportation in the late 1990's to perform a benefit-cost analysis for proposed major highway corridor projects. The new version of MCIBAS varies from its original model. In addition to developing a "Benefit–Cost Pre–Processor" to transfer the traffic data from the Indiana Statewide Travel Demand Model (ISTDM) to a Monetized User Benefits module, the new MCIBAS also replaces the "Net _BC" with a spreadsheet module, called the Simplified Economic Analysis Tool (SEAT). Therefore, the new version of MCIBAS has two approaches—***SEAT*** and ***REMI***—to reach the goal of conducting the economic evaluation of highway corridor projects.

The REMI approach works with the Monetized User Benefits module, Accessibility Pre-Processor, and Economic Impacts Analysis System (EIAS) to anticipate the economic-related outputs from the project. The Simplified Economic Analysis Tool (SEAT) adopts the results from the Monetized User Benefits module and uses economic multipliers to directly generate economic development impact outputs, such as GRP, employment, and income.

2.4.2.3.1 Advantages of MCIBAS. One big advantage of MCIBAS is that the separation of the REMI approach and Simplified Economic Analysis Tool (SEAT) provides users choices to estimate the economic impacts of projects at different levels of detail. Users can either quickly produce a simple economic value estimation for a project through the SEAT approach by considering benefits from changes in the link-level of vehicle-miles-traveled (VMT) and vehicle-hours- traveled (VHT), or obtain more comprehensive economic outputs by running the REMI approach first, and then adding the relative economic impacts results to the SEAT to account for the total benefits.

A second advantage of MCIBAS is that it includes four scenarios (base year no build, base year build, future no build, and future build) in project analysis. The clear differentiation of these scenarios empowers users to comprehensively estimate the project's impact on current and future situations. Results from the four scenarios help users to better understand the degree of impact the project would have on the surrounding regions under the current traffic conditions, as well as the future travel circumstances.

A third advantage of MCIBAS is that it considers the residual value of the project. This residual value is estimated by users, and it improves the accuracy of the benefits assessment of the project. Users can import this value on the project cost page of the SEAT.

A fourth advantage of MCIBAS is that the VMT and VHT are summarized by 2 mph speed-bin (40 total bins between 0 and 80 mph) in the "Benefit–Cost Pre–Processor" module. This makes it possible for users to analyze the monetary value of standard user benefits (travel time savings, vehicle operating costs savings, etc.) separately by a 2 mph speed-bin in the Monetized User Benefits module. Hence, users can see the travel time savings at each 2 mph speed-increment level.

Moreover, the Economic Impacts Analysis System (EIAS) of the MCIBAS-REMI approach is a rich database of information fundamental to conducting economic impacts evaluation of transportation projects in the state of Indiana. For instance, it contains the REMI forecast of Indiana employment for each integrated industry sector from 2005 to 2050. The Transportation Satellite Accounts (TSA) usage, which provides a means to estimate transportation production requirements from TSA is also provided by integrated industry sectors. Furthermore, the Indiana County Business Patterns Location Quotient, which is Indiana location quotients compared to national County Business Patterns data, is contained in the EIAS as well. These spreadsheets are well organized and structured as prerequired information for the economic development impacts evaluation later performed in the REMI Policy Insight.

One additional advantage of MCIBAS is that vehicle operating cost savings are calculated discretely by fuel component and non-fuel component. This distinction allows the analysis to attain a more accurate measure of fuel-related costs.

2.4.2.3.2 Limitations of MCIBAS. The limitations of MCIBAS are as follows.

- First, MCIBAS was designed specifically for the Indiana Department of Transportation, which may restrict its usefulness to other state agencies.
- Furthermore, MCIBAS has to be coordinated with a statewide travel demand model (e.g., the Indiana Statewide Travel Demand Model) and TransCAD to estimate the vehicle-miles-traveled (VMT) and vehicle-hours-traveled (VHT) at the link level for the four aforementioned scenarios (base year no build, base year build, future no build, and future build) for each transportation project, which is time consuming and hard to manipulate for the agencies that lack the skill sets for operating statewide Travel Demand Models or TransCAD.
- Moreover, the structure of MCIBAS requires users to integrate the Indiana Statewide Travel Demand Model (ISTDM), Benefit-Cost Pre–Processor, Monetized User Benefits module, Simplified Economic Analysis Tool (SEAT), Accessibility Pre-Processor, and Economic Impact Analysis System (EIAS) manually when evaluating the economic development impacts of a project. Users have to copy the outputs from one module to the other as inputs. This manual operation process may cause inadvertent errors.
- Fourth, MCIBAS is not able to fully study the wider economic benefits associated with a transportation project. The Accessibility Pre-Processor in the REMI approach only takes into account a portion of market access and demands a clearly separate measurement for travel time reliability. Variables included in MCIBAS to measure market access are travel time to the nearest major airport, travel time to the nearest major truck/rail intermodal facility, and employment within a 3-hour radius. These variables can only be used to estimate intermodal connectivity and buyer-supplier market access. Reliability and labor market access are not captured in this manner. Therefore, assessments of the potential benefits of reliability and labor market access are absent from MCIBAS.
- Fifth, the separation of business trips and non-business trips in MCIBAS cannot reflect the appropriate time value for all automobile trips. Based on the National Household Travel Survey (NHTS), trips for automobiles in general can be categorized into commuter trips, business trips, and personal trips. Business trips have the highest time value, while personal trips have the lowest. The rough categorization of only considering business trips and non-business trips for passenger cars in MCIBAS is acceptable for the economic development impacts analysis, but does not provide a detailed, comprehensive economic efficiency study.

Finally, there are only 70 integrated industry sectors in MCIBAS. The first 66 industry sectors are private-sector non-farm industries (REMI Codes 1-66). The government sectors (REMI Codes 67 to 69) are used to estimate personal tax reduction. Farm (REMI Code 70) is seen as a proxy of the projected increase in a proprietor's income. However, considering the objective of MCIBAS, the deficiency in the completeness of industry sectors is understandable. MCIBAS was designed for Indiana Department of Transportation planners at the early stage of project planning, and the integrated industry sectors are capable of meeting the needs that roughly assess the economic development impacts of proposed projects. Table A.2 in Appendix A indicates the case studies with applications of MCIBAS at the state level.

2.4.2.3.3 Comparison of TREDIS and MCIBAS. A comparison of TREDIS and MCIBAS is made based on data inputs and tool functionality. In terms of traffic data inputs, TREDIS is flexible and does not have to be combined with a travel demand model in order to generate the desired inputs. MCIBAS has to be combined with the ISTDM and TransCAD in order to produce vehicle-miles-traveled (VMT) and vehicle-hours-traveled (VHT) at the link level for further economic development impact analysis.

For its accessibility measurements, the Market Access Module in TREDIS captures the improvements of business production, labor productivity, and international exports in a study region by measuring access to labor, industrial suppliers and customers, intermodal facilities with domestic service, and international gateway facilities (Alstadt et al., 2012). Three regression models were developed with data from 3141 U.S. counties to evaluate the aforementioned objectives considering both market accessibility factors and connectivity factors (Alstadt et al., 2012). Two factors used by TREDIS to determine market accessibility are:

- the population within a 40–minute drive
- the employment within a 180-minute drive.

The labor market access benefits are measured by the size of local markets within a 40-minute drive from the population centroid of a county. The market access benefits from a domestic supply chain are measured by the total employment accessed within a 180–minute drive from the population center of a county. The factors that assist in calculating the connectivity include:

- access to a domestic airport,
- access to an intermodal rail facility,
- access to a major seaport, access to a major international airport, and
- access to an international land border (Alstadt et al., 2012).

TREDIS provides default values for the aforementioned variables in a no build case, but requires users to input the corresponding values for the build case. In contrast, because MCIBAS only measures a portion of market access and connectivity, the required data inputs are fewer than that of TREDIS. Users only need to identify travel time to the nearest major airport, travel time to nearest major truck/rail intermodal facility, and employment within a 3-hour radius for the future build and no build cases.

With regard to the tools' functionality, four basic modules (Traffic Cost, Market Access, Benefit-Cost, and Economic Adjustment) and three optional modules (Finance, Freight, and Forecasting) within TREDIS enable transportation planners to explore the economic value of a project with different emphasis, as well as to execute different types of analysis based on the specific requirements and unique features of the projects.

The Economic Impact Adjustment module is well suited to anticipate the impact of a transportation project on economic development, both in the short-term and long-term. The Benefit-Cost module in TREDIS utilizes the output from the Economic Impact module and can be used for any category of transportation project (EDRG, 2014a). MCIBAS, on the other hand, first assesses the standard user benefits in the Monetized User Benefits module, transferring the portion of user benefits as savings to either the Simplified Economic Analysis Tool (SEAT) or the Economic Impact Analysis System (EIAS) in the estimation of economic impacts.

- MCIBAS SEAT then conducts the final benefit-cost analysis that contains results from economic impacts analysis that also includes he productivity benefits generated from improved access to the buy-supplier market or the nearest intermodal facility.

In addition, TREDIS estimates reliability as one of branches of wider economic benefit using the interactions between buffer time index, congestion level for each combination of trip purpose and mode, and the ratio of vehicle-hours-traveled (VHT) and vehicle trips. As mentioned previously, MCIBAS does not indicate reliability in its design features, so it may require extra effort to evaluate complete wider economic benefits.

Lastly, in terms of analysis types, TREDIS excels in single project evaluation, project prioritization, long-term vision plan, alternative selection, policy evaluation, infrastructure assessment, asset management and freight planning. MCIBAS does not have a specific characterization for the range of analysis types, but its final output might be useful for single project evaluation, project prioritization, long-term vision plan, and policy evaluation. This comparison of TREDIS and MCIBAS is summarized in Table 2.4.

2.5 Past Research of Nontraditional Improvements

The wide variety of topics involved in Nontraditional corridor improvements determines its diversity. As aforementioned, operations strategies, nonphysical strategies, and strategies supporting infrastructure are considered the three major branches of Nontraditional corridor improvements. Most past studies have placed emphasis on assessing the economic efficiency of Nontraditional corridor improvements. This section presents a literature review, based on reports of States' Departments of Transportation, other agencies, and research papers on this topic.

Table 2.5 indicates recent studies on evaluating the economic efficiency of operations strategies. It can be seen that travel demand management strategies justify the investments with a generally high benefit-cost ratio. For instance, the economic analysis of the City of Anaheim Gene Autry Way (West) Highway/I-5 High Occupancy Vehicle Lane (HOV) interchange in California reported a benefit-cost ratio of 2.9 under a 7% discount rate and a ratio of 4.3 under a 3% discount ratio, respectively (City of Anaheim, California, 2009). Another application of Travel Demand Management strategies that incorporate the economic efficiency evaluation, the *Minnesota Urban Partnership Agreement* project, presents a benefit-cost ratio of 6.0 resulting from a series of improvements, including the addition of the MnPASS HOT lanes, new and expanded park-and-ride lots, new bus routes, and reconstruction of the crosstown commons section among others (Lawrence et al., 2015). The RITA benefits database, created and overseen by the U.S. Department of Transportation is another rich resource for the application of Nontraditional corridor improvements across states.

TABLE 2.4
Comparison of TREDIS and MCIBAS

Features	TREDIS	MCIBAS
Require a Travel Demand Model		×
Direct Economic Impacts	×	×
Indirect/Induced Economic Impacts	×	×
Full Wider Economic Benefits Evaluation	×	
Benefit-Cost Analysis	×	
Long-term Vision Plan	×	×
Policy Evaluation	×	×
Infrastructure Assessment	×	
Asset Management	×	
Freight Planning	×	
Multimodal Analysis	×	
Customized Mode Purpose Combination	×	
Other Regional Economic Models Embedded	×	×
Technical Support	×	
Staff Training for DOT		×
Portability	Web-based	PC-based

Table 2.6 shows a summary of case studies that involve operations strategies in Indiana. The arterial signal coordination case study on US 31 in Kokomo reported a $2.7 annual million savings from travel time (Day et al., 2010). The traffic incident management case study led by Purdue in 1999 generated a benefit-cost ratio of 4.7 in daytime operations and 13.3 during 24-hour operations (Latoski et al., 1998). Strategies supporting infrastructures, e.g., a traffic management center, have proven to be economically feasible as well.

A case study of the Florida Department of Transportation chose the Regional Traffic Management Center in District 4 to investigate the economic feasibility of several intelligent transportation system (ITS) strategies under its monitor and management. The target ITS strategies include Closed Circuit Television Cameras (CCTV), Dynamic Message Signs (DMS), a Vehicle Detection System, and SunGuide Software in all of the Traffic Management Centers (TMCs) in Florida. A 10.44:1 benefit-cost ratio proves that the traffic management center generates considerable benefits (Lawrence et al., 2015).

Comparing to the number of reports available, there are fewer research papers that concentrate on assessing the economic efficiency of nontraditional corridor improvements. Sunkari (2004), in a study on the benefits of retiming traffic signals, found that the benefit to cost

TABLE 2.5
Summary of Studies on the Economic Efficiency of Nontraditional Corridor Improvements

Project Type	Case Studies	Location	Year	Economic efficiency/economic impact
Interchange Modification	Interchange Modification Report for I-85 and SR 400	GA	2010	B/C = 5.33
HOV Lanes	An Evaluation of the Cost Effectiveness of HOV Lanes	WA	1988	The Marginal B/C >6 in all three study sites in Seattle
	HOV Performance Assessment through Operational, Environmental Impact and Cost-Benefit Analysis	AL	2010	20% HOV usage leads to the highest B/C ratio of 4.38 under the consideration of induced travel demand
	Benefit-Cost Analysis for Gene Autry Way (West) Highway/I-5 HOV Interchange Project	CA	2009	B/C = 2.9 under 7% discount rate B/C = 4.3 under 3% discount rate
HOT Lanes	HOT Lanes: A Comprehensive Evaluation of Costs, Benefits, and Performance	CA	2000	10-mile HOT lane facility can provide up to $20 million in annual revenue (in 2000 dollars)
	Benefit-Cost Analysis of Variable Pricing Projects: Quick Ride HOT Lanes	TX	2006	B/C = 1.7
Travel Demand Management	Minnesota Urban Partnership Agreement Project	MN	2015	B/C = 6.0

TABLE 2.6
Application of ITS Strategies in Indiana

ITS Implementation Strategies	Case Studies	Location	Year	Benefits
Commercial Vehicles Operations	Simulations Analysis of Congestion—Reduction Strategies at an Overload Weigh Station	Seymour, IN	1999	Implementing weigh-in-motion technology and equipping 40% to 50% of trucks with electronic screening transponders would significantly reduce queue flow
	Institutional Issues Affecting the Implementation of IVHS Technologies to Commercial Vehicle Operations in the State of Indiana	IN	1993	1. Total savings for a 65 mi/h WIM mainline bypass: $267.8 million 2. Savings for a 40 mi/h WIM offline sorting: $231.2 million 3. Savings for a 20 mi/h WIM offline sorting: $137 million 4. Potential maximum annual safety savings in Indiana: $3.8 million 5. Typical state benefits: $3.6M - $5.5M 6. Typical motor carrier benefits in compliance requirements of AVI: $17.7M to $53.0M 7. Indiana could also gain $22.1 million annually from additional violation citations brought about by better enforcement
	Estimating Cost Savings From Advanced Vehicle Monitoring and Telecommunications Systems in Intercity Irregular Route Trucking	Indianapolis	1992	Several carriers reported that on-board monitoring systems enable carriers to increase loaded mileage by 9% to 16%, decrease operating costs, and save drivers time in reporting their status to dispatchers
Traffic Incident Management	Cost-Effectiveness of Hoosier Helper Freeway Service Patrol	Gary, IN	1999	Daytime operations B/C = 4.7 24 hours Operations B/C = 13.3
Arterial Management	Performance Measures for Traffic Signal Systems: An Outcome Oriented Approach	US 31 Kokomo, IN	2014	Total travel time savings is $2.7 million. Total CO2 reduction savings is $21,596.03
	Best Practices for Road Weather Management, Version 3	IN	2012	1. Reduced total winter maintenance budget by 27% for an estimated $11 million savings by implementing a Maintenance Decision Support System (MDSS). 2. A case study of New Hampshire's five previous winters showed that, had MDSS been used, 23% less salt could have provided the same level of service; alternatively, the incidence of "unacceptable" driving conditions could have been reduced by 10%–15% with equal salt use. In either case, the overall B/C = 8
	Maintenance Decision Support (MDSS): Indiana Department of Transportation (INDOT)—Statewide Implementation—Final Report for FY 09	IN	2009	In Indiana during the 2008–2009 snow and ice season, the implementation of a MDSS resulted in statewide savings of salt usage $9,978,536 (188,274 tons) and overtime compensation from the previous winter season $979,136 (41,967 hours)
	Technology in Rural Transportation 'Sample Solutions'	IN	1997	Equipment and operating cost for winter maintenance has been reduced by $11 to $14 million

Source: FHWA, n.d.b.

ratio is about 40:1. The performance of an advanced traveler information system (ATIS), a group of techniques to collect and process data from a transportation network first and then disseminate the relevant information to travelers in Los Angeles, California was explored. The results of the case study indicate that ATIS is able to provide approximately 14% of extra travel time savings compared to the no-build situation. In addition, a 50% reduction in travel time variability can be expected with an ATIS, depending on the type of traveler information (Toledo & Beinhaker, 2006).

The benefit cost analysis of Highway Occupancy Vehicle Lane (HOV) performance under different scenarios in the Birmingham, AL region shows that either converting the existing lanes to HOV lanes or adding additional HOV lanes is profitable (Sisiopiku, Cavusoglu, & Sikder, 2010).

Lavrenz, Day, Smith, Sturdevant, and Bullock (2016) applied a five-year signal timing plan for traffic signals on State Road (SR) 37 in Indiana to investigate the potential benefits of signal retiming. A 5% reduction of travel time costs and reliability were found after each optimization, which further led to $3.6 million in overall user benefits over a 5-year period.

Turning to access management, safety benefits and operation benefits are two major contributing factors that often lead to a high economic efficient assessment. The 1997 report of Iowa Access Management Awareness Program states that crash rates were reduced 40% on average for all projects following access management implementation. Noted here too are the noteworthy operational benefits achieved by raising of the level of service at peak hours (CTRE, 1997). In *Evaluation of Access Management,* the Houston-Galveston Area Council and Texas A&M Transportation Institute similarly concluded that access management reduced collisions as well as benefits on operations (Houston-Galveston Area Council and Texas A&M Transportation Institute). In 2006, the Kentucky Transportation Center published the results of national research on the effects of common access management in the "*Quantification of the Benefits of Access Management for Kentucky*" (Kirk, Jerry, & Barry, 2006). Table 2.7 summarizes the safety effects of access management strategies.

Different from access management, road diet has not been seen to improve traffic operations. In spite of this, considerable safety benefits generated from a typical road diet implementation is proven by numerous case studies. There is a consensus that if a roadway segment is overwhelmed by heavy traffic, the related operations loss (i.e. congestion, delay, and unreliability) will exceed the safety benefits of implementing a road diet. However, debates exist on the upper limit value of ADTs (Average Daily Traffic) required for implementation.

TABLE 2.7
Effects of Common Access Management Strategies

Treatment	**Effect**
1. Add continuous two-way left turn lane (TWLTL)	35% reduction in total crashes 30% decrease in delay 30% increase in capacity
2. Add non-traversable median	35% reduction in total crashes 30% decrease in delay 30% increase in capacity
3. Replace TWLTL with a non-traversable median	15%–57% reduction in crashes on 4-lane roads 25%–50% reduction in crashes on 6-lane roads
4. Add a left-turn bay	25%–50% reduction in crashes on 6-lane roads Up to 75% reduction in total crashes at unsignalized access 25% increase in capacity
5. Type of left-turn improvement a. painted b. separator or raised divider	a. 32% reduction in total crashes b. 67% decrease in total crashes
6. Add right-turn bay	20% reduction in total crashes Limit right-turn interference with platooned flow, increased capacity
7. Increase driveway speed from 5 mph to 10 mph	50% reduction in delay per maneuver Less exposure time to following vehicles
8. Visual cue at driveways, driveway illumination	42% reduction in crashes
9. Prohibition of on-street parking	30% increase in traffic flow 20%–40% reduction in crashes
10. Long signal spacing with limited access	42% reduction in total vehicle-hours of travel 59% reduction in delay 57,500 gallons fuel saved per mile per year

Source: Kirk et al., 2006.

For a four-lane to three-lane road diet conversion, Michigan studies suggest that the maximum permissible ADT is 10,000. More importantly, a four-lane to three-lane road diet conversion increases delays significantly when peak hour volume exceeds 1,000 (or somewhere between 1,000 and 1,500) (Lyles et al., 2012). Nevertheless, the literature review compiled for *Safety and Operational Analysis of 4-lane to 3-lane Conversions (Road Diets) in Michigan* takes a controversial stand regarding the most plausible value of ADT discovered in many places. For instance, the Montana Department of Transportation (DOT) announced that an ADT of 18,000 in a commercial area still maintains a good traffic flow, and the surrounding communities were in favor of the 3-lane roadway based on their 1999 experience on US-12 in Helena. Later on, when Knapp et al. (2014) investigated the feasibility of an urban minor arterial four-lane undivided into a three-lane conversion in 2003, the recommended ADT value with least operational risk was reported as 10,000 via CORSIM simulation analysis. Stout challenged Knapp's conclusion based on Iowa case studies by proclaiming in 2006 that "successful road diet conversions are more likely to occur when the traffic volume is generally less than 20, 000 ADT and there are large turning volumes". Road diet could work fine on roadways up to 24,000 ADT; with the consideration, however, that operational risk starts at 20,000 ADT. Dispute exists in the estimation of most acceptable ADT value over peak periods, too. For example, Knapp stated that road diet would be a wise choice as long as the peak-hour ADTs are in the 7500-8750 range, but cautions an ADT that surpasses 8750 (Lyles et al., 2012). Obviously, Michigan DOT disagrees with this announcement, as they decided to adopt 1,000 ADT as an acceptable upper limit of peak-hour traffic volume.

The Federal Highway Administration (FHWA) also advises that roadways with an ADT of 20,000 or less may be good options for a road diet, and decisions regarding feasibility should be made upon the evaluation. As for peak hours, Knapp's conclusion (7500-8750 ADT) is more recognized (Knapp et al., 2014). Other key findings from the literature review include that traffic volume is more or less consistent after a road diet conversion (Welch, 1999), and commonly used measures of road diet implementation impacts are Empirical Bayes and Full Bayes approaches for Before-After analysis (Persaud, Lan, Lyon, & Bhim, 2010). Table 2.8 indicates the crash rate range weighed by AADT (Annual Average Daily Traffic) according to FHWA's crash statistics produced from 15 Iowa treatment sites and 30 HSIS treatment sites in 2010.

This literature review of benefit-cost analysis implemented that road diet can be very economically beneficial due to its high rates of collision reduction and low construction costs. In 2015, Andrew Desmond and Brian Hutchinson reported $102.1 million in safety benefits and $31.2 million saved in travel costs over a 20-year period; these figures amount to a net benefit of $70 million from the 2.5 mile of Rainier Avenue south in Seattle, WA (Desmond & Hutchinson, 2015).

TABLE 2.8
Descriptive Statistics of Evaluated Road Diet Sites

Database/Site Type	Characteristics	Mean	Minimum	Maximum
Iowa Treatment (15 sites)	Years before	17.53	11.00	21.00
	Years after	4.47	1.00	11.00
	Crashes/mile–year before	23.74	4.91	56.15
	Crashes/mile–year after	12.19	2.27	30.48
	AADT before	7,987	4,854	11,846
	AADT after	9,212	3,718	13,908
	Average length (mi)	1.02	0.24	1.72
Iowa References (296 sites)	Years	21.8	5	23
	Crashes/mile-year	26.8	0.2	173.7
	AADT	8,621	296	27,530
	Average length (mi)	0.99	0.27	3.38
HSIS Treatment (30 sites)	Years before	4.7	1.8	8.5
	Years after	3.5	0.6	8.8
	Crashes/mile–year before	28.57	0.00	111.10
	Crashes/mile–year after	24.07	0.00	107.62
	AADT before	11,928	5,500	24,000
	AADT after	12,790	6,194	26,376
	Average length (mi)	0.84	0.08	2.54
HSIS Reference (51 sites)	Years	7.82	4.50	12.17
	Crashes/mile-year	42.19	5.96	169.73
	AADT	15,208	1,933	26,100
	Average length (mi)	0.95	0.10	3.31

Source: FHWA, 2010.

3. TOOL DEVELOPMENT

3.1 Conceptual Framework

A proposed conceptual framework for the evaluation of the economic development impacts of Nontraditional corridor improvements is shown in Figure 3.1. The proposed framework applies to nontraditional improvements considered at the corridor level. In terms of time horizons, the recent U.S. Department of Transportation TIGER (Transportation Investment Generating Economic Recovery) Grant application process suggested a 20-year time horizon for a traditional benefit-cost analysis. However, applying this recommendation to the benefit-cost analysis of nontraditional corridor improvements is difficult because most nontraditional corridor improvements are highly related to technology, which needs to be replaced on much faster cycles (e.g., every 2 to 5 years).

Moreover, unlike the practically static yearly benefits of capacity improvement projects, the benefits of nontraditional corridor improvements can vary from year to year. For instance, the benefits of adopting a freeway service patrol program (one sub-strategy of traffic incident management) can be different each year depending on the number of incidents in the study area.

Last but not least, initial cost estimation of the technology involved the target nontraditional corridor improvement may become inaccurate in future years as the result of technological advancement or innovation (FHWA, 2012).

Given this context, the best approach to appropriately conduct a benefit-cost analysis for nontraditional corridor improvements, before evaluating their corresponding economic impacts, is to use average annual benefits and costs, which are first estimated as a present value of a single year and then assume to be same for all analysis years (FHWA, 2012). Those performing the analysis can determine the most suitable time horizon for the chosen nontraditional corridor improvement on a project by project base. A comprehensive review of the conceptual framework components is presented in the following sections. Please refer to Section 2.2 for the definition of nontraditional corridor improvements.

3.1.1 Classification of MOEs by Benefit Types

This report classifies measures of effectiveness (MOEs) based on their types of benefits and presents a process to include travel time reliability in the evaluation of their economic development impacts. Among all components

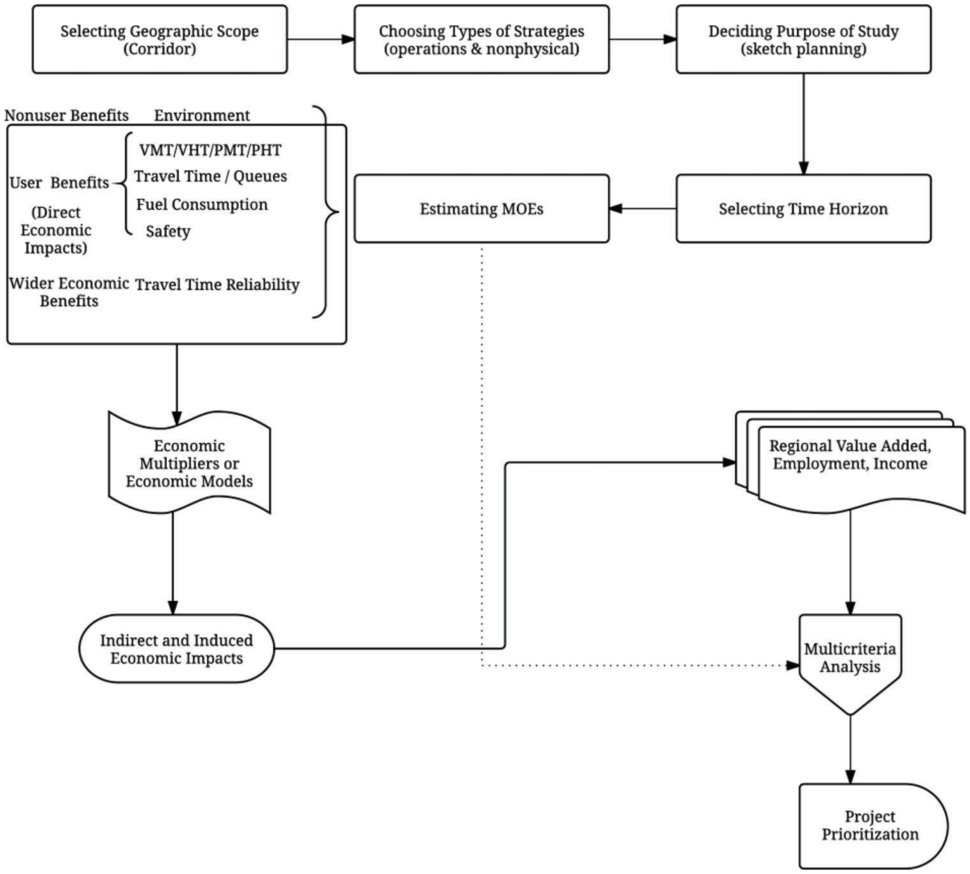


Figure 3.1 Proposed conceptual framework for the evaluation development impacts of nontraditional corridor improvements.

aforementioned in Section 3.1, the selection of the MOEs is a critical step in this process. According to the Operations Benefit/Cost Analysis Desk Reference published by the Federal Highway Administration in 2012 (FHWA, 2012), frequently adopted MOEs can be grouped into three categories:

- Traditionally recognized MOEs: User travel time savings, user vehicle operating costs, crashes, and emissions are usually treated as traditionally recognized MOEs. While the benefits of the reduction of emissions can justify investing on a project, they cannot necessarily stimulate the economic development in a region. Therefore, emissions will not be considered as an MOE when evaluating the impact on economic development.
- Emerging MOEs: Travel time reliability and induced travel/consumer surplus fall into the category of emerging MOEs. Travel time reliability is a relatively newer concept compared to the traditionally recognized MOEs mentioned previously. Travel time reliability is defined in Section 2.1.3.1. Consumer surplus occurs when induced travel is generated through mode shifts or route changes from parallel roadways because of a transportation improvement. It is on account of the "difference between what consumers are willing to pay for a good or service (indicated by the position on the demand curve) and what they actually pay (the market price)" (Sinha & Labi, 2007).
- Hard-to-quantify MOEs: The following MOEs are more difficult to quantify: community livability, customer satisfaction, and traveler perceptions of safety and security. Figure 3.2 shows the objectives of nontraditional corridor improvements and their corresponding primary and secondary impacts on different MOEs.

The frequently adopted MOEs for the benefit and cost analysis of Nontraditional corridor improvements can also be classified in three groups:

- User benefits: User benefits include travel time savings, safety savings, and vehicle operating costs savings (mostly fuel consumption savings). However, it must be noted that, for passenger cars, only travel time savings and safety savings for business-related trips and vehicle operating cost savings can be further converted into economic development impacts. For trucks, benefits of all trip purposes are considered when we are converting user benefits to the economic development impacts.
- Nonuser benefits: Nonuser benefits typically involve environment benefits, such as emissions.
- Wider economic benefits: The wider economic benefits specifically refer to an increase in travel time reliability. Recent studies, particularly the Strategic Highway Research Program 2 (SHRP2) have demonstrated how the improvement of reliability leads to productivity gains in a region. In summary, the MOEs that measure user benefits or wider economic benefits, and can be utilized to evaluate the impact of Nontraditional corridor improvements on economic development, are travel time savings of business-related trips, vehicle operating cost savings, safety benefits of business-related trips, and travel time reliability.

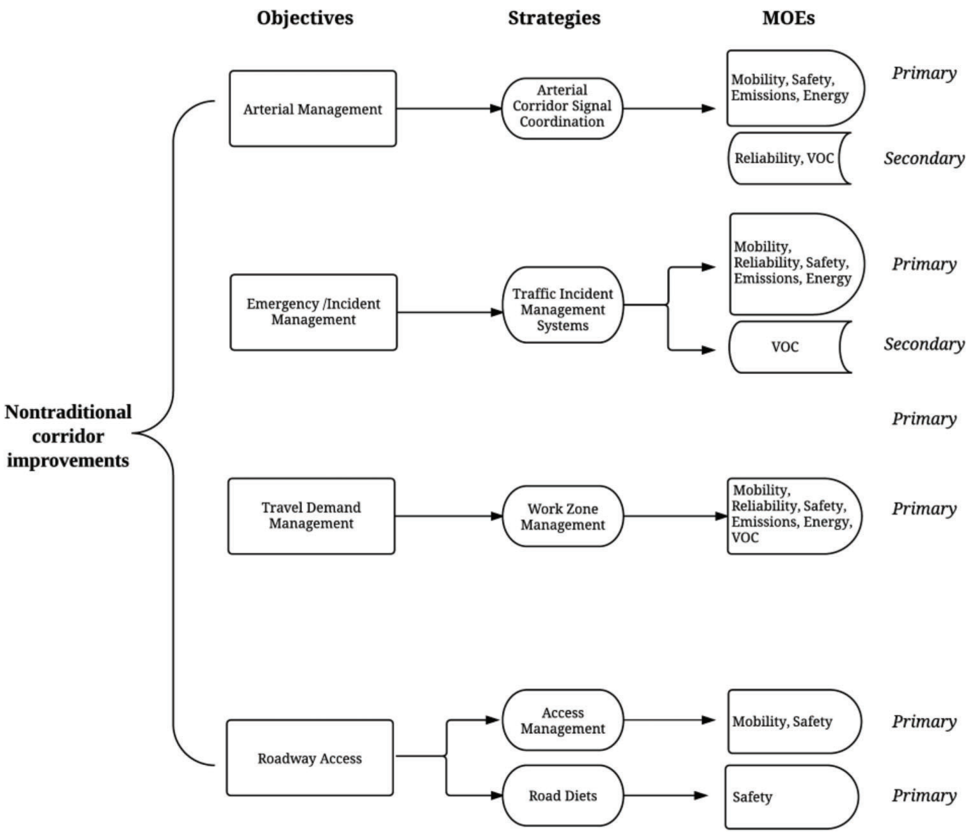


Figure 3.2 Nontraditional corridor improvements and MOEs.

3.2 Tool Development Strategies

As introduced in Chapter 2, the use of economic multipliers is important for the conversion of highway standard users' benefits to their corresponding economic development impacts. The following suggested options for tool development reflects this critical feature by showing various combinations of economic development multipliers and different economic analysis tools.

3.2.1 TOPS-BC-Based Approach

3.2.1.1 Comparison of TOPS-BC and IDAS. TOPS-BC and IDAS are tools that have been broadly adopted across different agencies. They were developed by FHWA. Table 2.1 in Chapter 2 outlined some key differences between TOPS-BC and IDAS; an expanded discussion about comparison of TOPS-BC and IDAS is stated herein. At the time this report was written:

- TOPS-BC is free and IDAS charges a license fee.
- Besides the discrepancy in costs, several other differences should be also noted:

1. First, IDAS is a post-processor of traffic data from the Travel Demand Model (TDM) that evaluates the economic efficiency of Intelligent Transportation System (ITS) strategies. By contrast, TOPS-BC is a spreadsheet-based accounting tool for estimating the economic efficiency of a broader spectrum of nontraditional corridor improvements.
2. TOPS-BC, analyzes the intelligent transportation strategies covered by IDAS but also includes other commonly-used operations strategies (e.g., High Occupancy Toll lanes). However, IDAS can provide a more accurate estimation of ITS strategies than TOPS-BC. The combination of IDAS with a Travel Demand Model (TDM) allows IDAS to conduct the relevant economic feasibility studies with more detailed traffic data provided by the TDM.
3. With respect to the geographic scope of an analysis, IDAS can be applied at the statewide, regional, corridor, and isolated location levels; TOPS-BC only functions at corridor and isolated location levels. It should be noted that the wide variety of Nontraditional corridor improvements covered by TOPS-BC makes it the most capable tool for evaluating the economic efficiency of a list of alternatives at the sketch planning stage.
4. Compared to TOPS-BC, IDAS is limited in its capability to assess the economic feasibility of Nontraditional corridor improvements in the categories of Travel Demand Management strategies or operational improvements.

3.2.1.2 The Merits of TOPS-BC. Beyond the comparison with IDAS, TOPS-BC excels in the following areas as well:

1. TOPS-BC provides default values for each input. These default values are developed from the literature review of relevant national research, and they assist users in evaluating Nontraditional corridor improvements with less effort but with efficient outcome generation. This feature is extremely useful for agencies that are not able to gather completely local information about the impacts of deploying the Nontraditional corridor improvement.
2. TOPS-BC clearly isolates the benefits of recurring congestion from the nonrecurring congestion. This separation allows users to distinguish the benefits of traditional delay (peak-hour) from the non-traditional delay (incident-related). The reliability benefits are then estimated accordingly.
3. TOPS-BC provides users with a choice to assess several different Nontraditional corridor improvements on the same page named as "My Deployment". The comparison of benefit-cost ratios for Nontraditional corridor improvements aids users in selecting the most economic efficient strategy.
4. TOPS-BC has been a developed and updated on a regular basis by the Federal Highway Administration. Figure 3.3 shows this combination.

3.2.2 MCIBAS-Based Approach

Section 2.4.2.3 described MCIBAS in terms of its overview, advantages, and limitations. MCIBAS takes

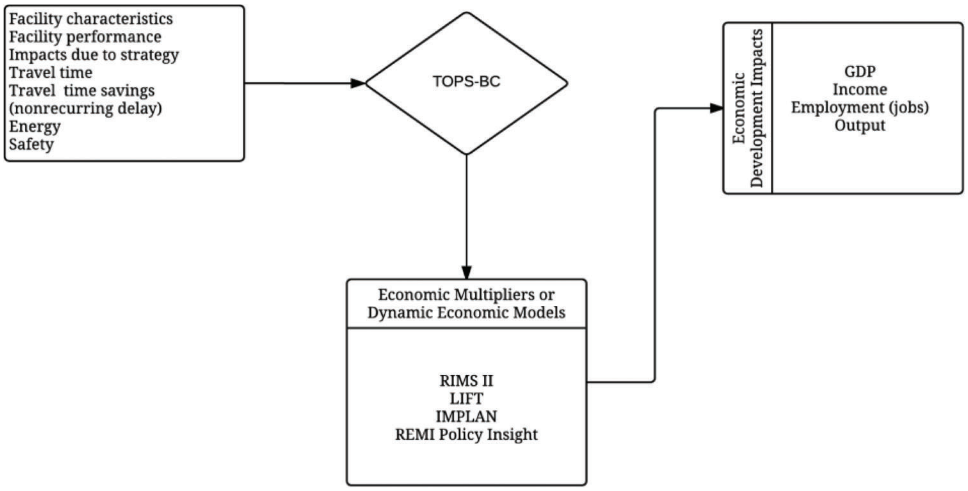


Figure 3.3 TOPS-BC–based approach.

vehicle miles traveled (VMT), vehicle hours traveled (VHT), and number of crashes from a travel demand model as inputs to process a post economic related analysis.

The principal objective of MCIBAS is to generate an economic development impacts analysis of capacity improvement projects. However, with a proper adjustment the tool can be applicable for the economic impacts evaluation of Nontraditional corridor improvements. For example, it is well known that the operational life of most Nontraditional corridor improvements is 3 to 5 years, as is the case for intelligent transportation system (ITS) related strategies (FHWA, 2012). Therefore, the current version of MCIBAS can be customized accordingly.

Additionally, because the majority of Nontraditional corridor improvements are designed to ease traffic congestion and improve travel time reliability, the measurement of Nontraditional corridor improvements' impact on reliability is essential when considering different evaluation approaches. MCIBAS does not have the capacity of evaluating benefits that result from improvement in reliability, but this limitation can be overcome as follows.

The final report *SHRP2 Travel Time Reliability Analytical Product Implementation* states that using the forecasted travel time reliability adopted in SHRP2 project C11, IDAS' look-up table is the only resource that matches ITS strategies with the corresponding average incident-related delay (Cambridge Systematics, Inc., & Kittelson & Associates, Inc., 2015).

The IDAS incident delay analysis generates a series of look-up tables containing estimates of the amount of potential incident-related delay for a facility on a per VMT basis. After a long-term monitoring and analysis of incident delay occurred on a number of national freeway corridors, the developers of IDAS (FHWA) generated rates that reflect the relationship between volume to capacity ratio, number of lanes, and predicted number vehicle hours of incident delay per vehicle miles traveled. Two inputs (volume to capacity ratio and number of lanes) are critical for the projection of number of vehicle hours of incident delay per vehicle miles traveled due to subsequent reasons.

- First, the volume to capacity ratio approximates the level of base congestion. A higher volume to capacity ratio is likely to result in higher incident-related rates, because it would be expected that a heavily congested roadway segment is going to be affected by incidents and it likely involves longer clearance time to clear an incident (or has longer incident duration period).
- Second, facilities with a greater number of lanes are able to better handle the consequence of incidents than that with fewer lanes. Assuming two identical incidents that occurred on a single lane of both a two-lane and a four-lane facility, the available capacity of the two-lane facility would reduce by one-half but the available capacity of the four-lane facility only reduces by one-quarter (FHWA, 2012).

The addition of the IDAS look-up table to MCIBAS will offset the shortcoming of reliability. It is noteworthy that the MCIBAS approach stands out from the existing economic multipliers in the MCIBAS SEAT approach and from the MCIBAS REMI approach, both of which can be applicable to evaluate economic development impacts of Nontraditional corridor improvements for sketch planning purposes. Figure 3.4 reflects the complexity of this option. However, for the option of MCIBAS plus reliability calculation, the outputs of from ISTDM (Indiana Statewide Travel Demand Model) must be recalculated to fit the input requirements of Nontraditional corridor improvements. Furthermore, the Indiana Department of Transportation has invested significant resources in developing MCIBAS for highway capacity projects; therefore, it is worthwhile to explore a completely different tool for Nontraditional corridor improvements. Last but not least, the MCIBAS approach is only suitable for Indiana. Other states cannot use this approach. In comparison, MCIBAS requires more preset work than the TOPS-BC approach.

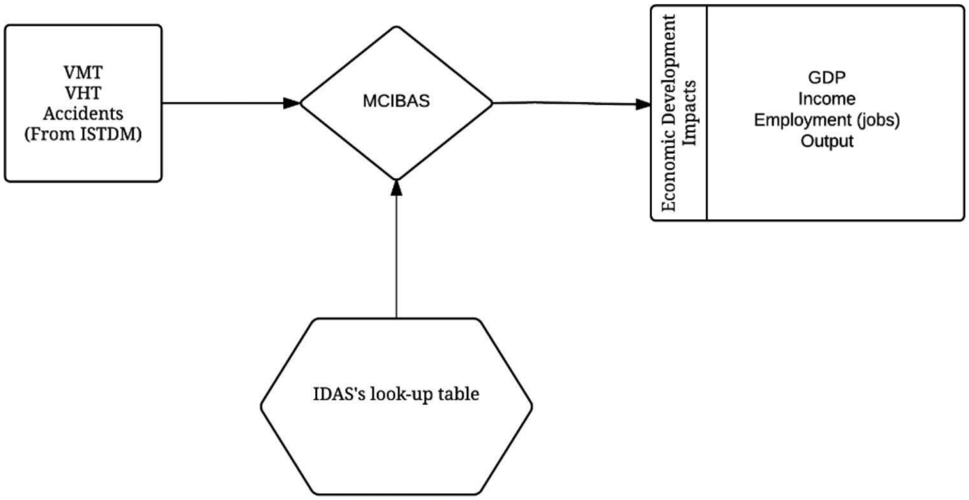


Figure 3.4 MCIBAS-based approach.

3.2.3 TransModeler-Based Approach

The third option for tool development is based on using TransModeler, a traffic simulation tool. Several highlights of TransModeler include its capability to model both large and small networks, simulate a variety of automobiles, integrate GIS (Geographical Information System) and travel demand software, and visualize flow and operations (Caliper, 2016). However, this option requires that users provide the network information before using TransModeler. The network information is usually available in a travel demand model (e.g., the Indiana Statewide Travel Demand Model).

TransModeler is equipped to analyze only several nontraditional corridor improvements, such as managed lanes, reversible lanes, and advanced traffic and management devices (dynamic message signs, ramp metering). Moreover, TransModeler cannot be used for a benefit-cost analysis. In this context, an external tool for benefit-cost analysis is required. Redbook Wizard and MCIBAS are recommended supplements. Nevertheless, neither can be used directly (without calibration) due to a lack of discrete evaluation of travel time reliability benefits. The option of adding travel time reliability to the tool development was discussed in the previous section. REMI Policy Insight, IMPLAN or RIMS II can be used for the economic development impacts conversion, too. Figure 3.5 explains this combination in more detail. For the option of TransModeler plus the benefit-cost analysis and economic multipliers, a few drawbacks make it less attractive than TOPS-BC. As Figure 4.3 displays, network information has to be prepared for TransModeler. Likewise, the first weakness of MCIBAS approach, its recalculation of ISTDM outputs, is also desired in order to generate the proper inputs for the economic development impacts evaluation of nontraditional corridor improvements. Moreover, recall that this option also necessitates the integration of Redbook or MCIBAS.

The complex combination and coordination of three tools (ISTDM, TransModeler, and Redbook Wizard or MCIBAS) is a challenge. Analysts must integrate the three tools and adjust them accordingly for the analysis. It is worth stating that the calculation of reliability has to be complemented as well, so analysts face the aforementioned complications for including calculations of reliability again in this case. Finally, the few Nontraditional corridor improvements that can be analyzed by TransModeler are limited in both the ITS and travel demand strategies area. In summary, Trans Modeler seems to be the most complicated and difficult option for tool development. The TOPS-BC approach, on the other hand, was designed specifically for econo mic efficiency evaluations of nontraditional corridor improvements. High-level classification of ITS strategies, such as arterial signal coordination, traffic incident management, and work zone management, gives the program more extensive applications.

3.2.4 TREDIS-Based Approach

In Section 2.4.2.1, TREDIS was introduced and its features, advantages, and drawbacks were discussed. In terms of the economic development impacts evaluation of nontraditional corridor improvements, TREDIS is superior as a stand-alone application. Similar to the analysis of other types of transportation projects, TREDIS requires users to decide the major improvement to the transportation system through the implementation of nontraditional corridor improvements. For example, for traffic incident management, the foremost improvement to the transportation system is reliability. An accurate estimation of the percentage of congestion for different combinations of trip purpose and mode

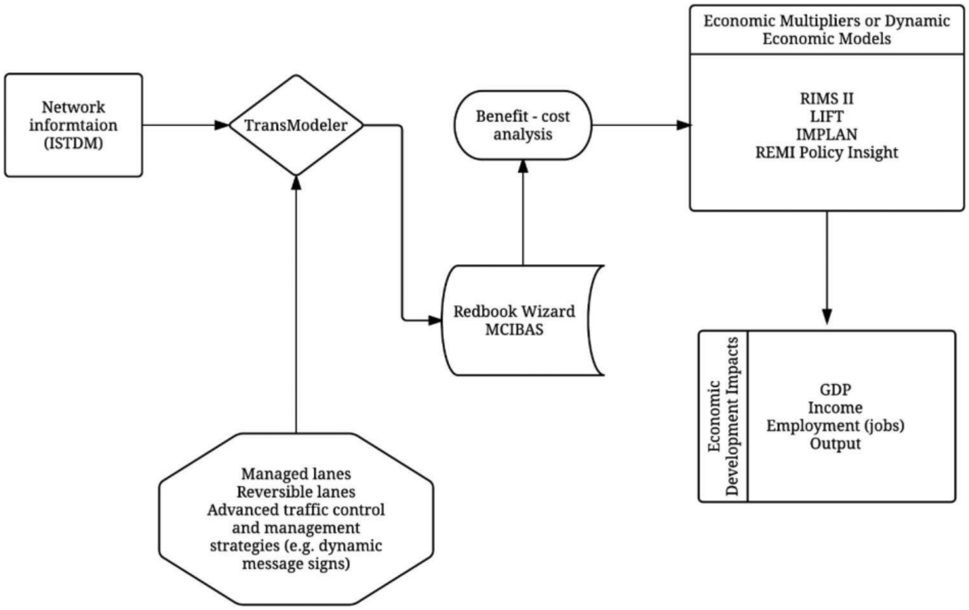


Figure 3.5 TransModeler-based approach.

play a significant role because TREDIS uses this value in its reliability cost calculations. Users must also estimate travel time savings of implementing the traffic incident management in the form of vehicle hours traveled (VHT) or travel speed (mph). These values are imported for different combinations of trip purpose and mode as well. TREDIS robustly converts the highway standard user benefits into the associated economic development impacts. Paired with CRIO-IMPLAN, TREDIS completes the economic efficiency and economic development impacts analysis without the support of other tools.

Generally, the required inputs for TREDIS to accomplish the above analysis include project background information, traffic volume, affected travel distance, travel time, and congestion level. With regard to the measurement to wider economic benefits, the Market Access Module enables TREDIS to evaluate how the implementation of nontraditional corridor improvements would improve access to labor markets, buyer-supplier markets, and enhance intermodal connectivity of the study region. However, users have to estimate "population that can be reached within a 40-minute drive", "employment that can be covered within a 3-hour drive", and "average drive time to the intermodal facility contained in the study region" after the application of nontraditional corridor improvements respectively. Figure 3.6 features this option.

One of the biggest shortcomings of TREDIS is that it requires users to import the travel time changes and the congestion level for each combination of trip purpose and mode. The travel time benefits and travel time reliability benefits are then calculated based on these inputs. TOPS-BC, however, provides a default value as well as a range of speed changes for each incorporated nontraditional corridor improvement and estimates reliability benefits led by incident-related delay through the look-up table in IDAS. Travel time benefits are accounted for in a table which describes the speed-flow relationships and was developed through resources in 2010 Highway Capacity Manual. Users can either use the default value, which was recommended by national research findings or overwrite it with the local value from the case study.

Moreover, TREDIS does not convert the safety benefits from business trips of passenger cars to economic development impacts; the reduction in crashes is assumed to lead to a loss of jobs for industries such as auto-repair shops and insurance companies (EDRG, 2014d). The statement is only correct to a certain extent, but a reduction in crashes can also lead to increased productivity and reduction in worker absenteeism and insurance costs. Last, TREDIS is not a free tool. Users have to pay a license fee. Therefore, TOPS-BC is a tool more suitable for nontraditional corridor improvements at the sketch planning stage.

In view of the above, it can be concluded that the TOPS-BC-based approach is the best candidate for the economic impact evaluation of nontraditional corridor improvements. This report presents in great detail the different components of this approach and their requirements (Sections 4.3–4.5), demonstrates this approach using two case studies in Indiana (Chapter 5), and outlines future research directions for enhancing this approach (Chapter 6).

3.3 Categorization of Benefits in the TOPS-BC-Based Approach

The measures of effectiveness regarding travel time benefits (recurring travel time benefits) and travel time reliability benefits (nonrecurring travel time benefits) involved in the research framework are further differentiated by both trip purpose (business trips and other trips) and mode (passenger cars and trucks).

The National Cooperative Highway Research Program Report 456 states that there are five specific factors in transportation projects that have influence on the impacts of a region's economic development (Forkenbrock & Weisbrod, 2001):

1. Business travel costs,
2. Business market reach,
3. Personal travel costs,
4. Job access, and
5. Quality of life

An economic development impact evaluation of a transportation investment should be carried out by considering one or more of these five factors (Forkenbrock

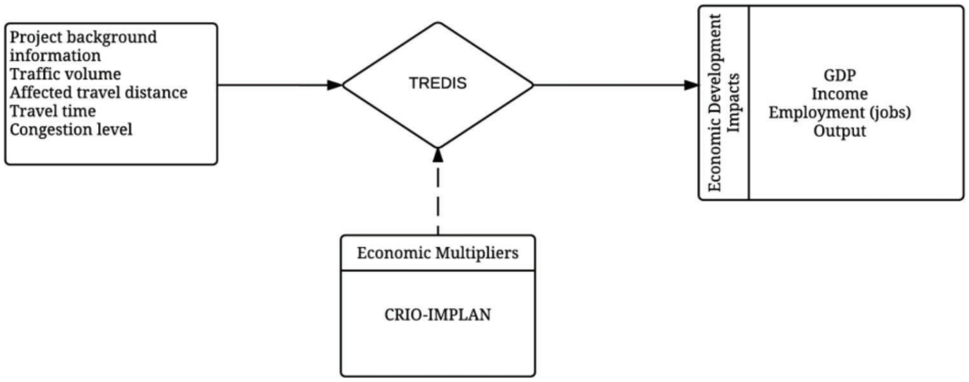


Figure 3.6 TREDIS-based approach.

& Weisbrod, 2001). However, it should be noted that a clear distinction of (1) factors that directly affect money flows and (2) factors that have a social value (expressed as "willingness to pay") but not direct affect money flows (SHRP2, 2014) is critical prior to performing an economic development impacts analysis.

Factors that that have direct effects on money flow are business travel costs, business market reach, and job access. These factors can be further placed in the following savings categories: savings in vehicle operating costs, travel time savings in business or on-the-clock trips (trips paid by organizations rather than the driver), travel time savings of truck trips, savings from improvement of travel time reliability, productivity from expanded access to buyer-supplier market access, and productivity from enhanced access to labor markets. Productivity is a ratio of generated output to the input as a proxy of business efficiency (NCHRP, 2014). Nonetheless, factors that do not have direct effects on money flows are personal travel costs and quality of life. Travel time savings during a personal trip will not necessarily have a noticeable effect on job creation in the study region, therefore benefits from savings in recurring travel time of personal passenger car trips are better reflected by societal impacts than by economic impacts. As displayed in Figure 3.7, recurring travel time benefits from other trips (i.e., personal trips) are not counted in the user benefits conversion to the direct economic impacts. Nonrecurring travel time benefits of business and commute trips compensate with travel time reliability benefits, which can lead to business productivity. Almost all of truck trips are meant to improve the productivity without distinction of trip purpose.

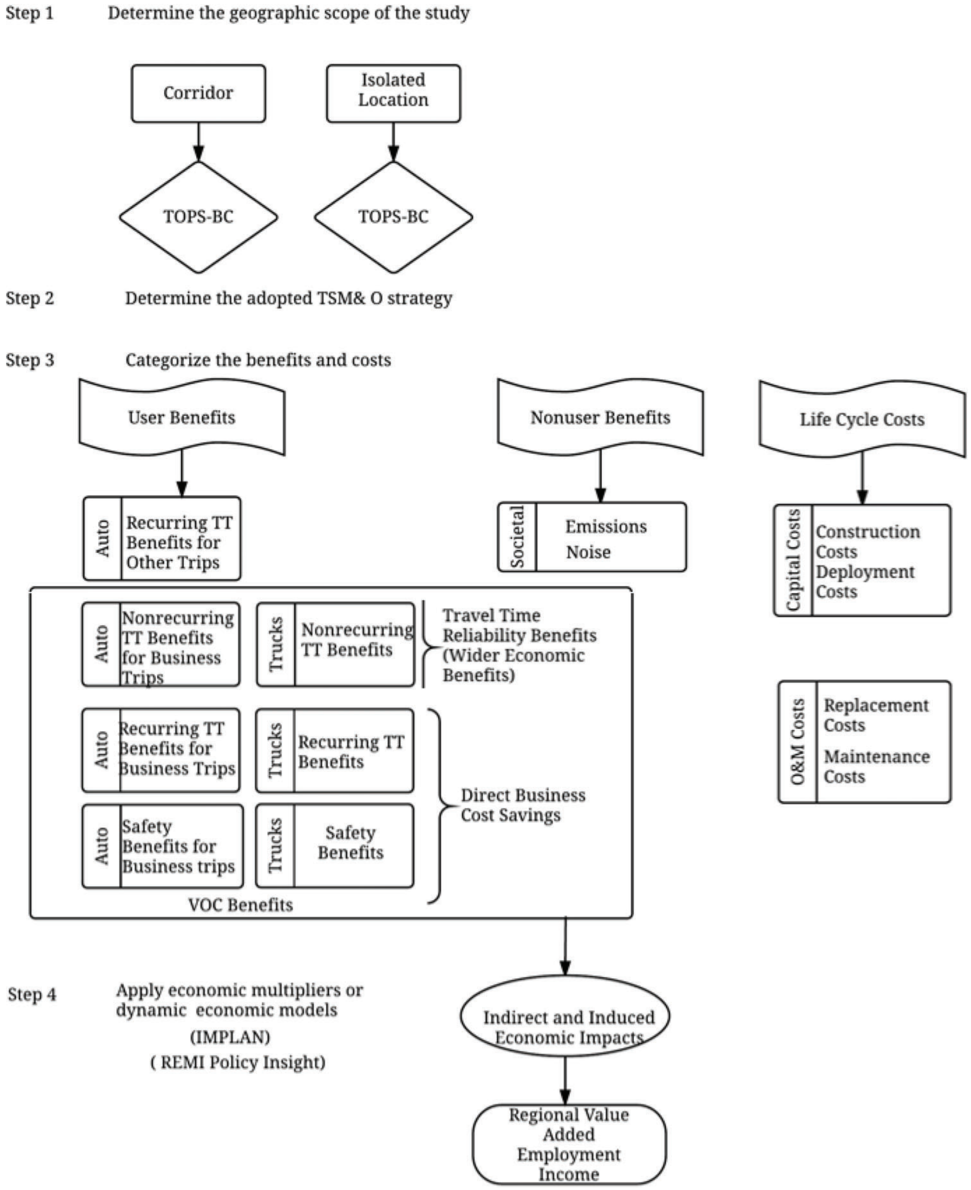


Figure 3.7 Proposed framework for evaluating the economic development impacts of nontraditional corridor improvements.

3.3.1 Data Inputs and Default Benefits Calculation Using TOPS-BC

After establishing a good understanding of how to appropriately categorize benefits in order to correctly convert the benefits into economic development impacts, it is necessary to understand how TOPS-BC analyses included nontraditional corridor improvements in terms of benefits covered in Figure 3.1. Refer to Section 2.2 for the full list of nontraditional corridor improvements included in this report. Agencies, such as the Indiana State Department of Transportation, may desire to know the benefit evaluation capabilities of TOPS-BC per project need in order to determine which strategy should be adopted.

Table 3.1 and Table 3.2 are developed to meet this purpose. Table 3.1 shows that not all nontraditional corridor improvements feature default travel time reliability benefit calculations. Also, more data inputs are required for ramp metering and HOT lanes than for other strategies. Table 3.2 shows the evaluation of benefits associated with nontraditional corridor improvements. The benefits that can be automatically calculated in TOPS-BC are indicated as "yes." Other benefits that can be added to the calculation as an option are marked with the symbol "ʘ" in the table.

3.3.2 Economic Multipliers and Dynamic Economic Model

This section presents the selected economic multipliers employed in the framework of a TOPS-BC approach. REMI Policy Insight was selected among the dynamic economic models (refer to Section 3.2.2 for the full list of economic multipliers and dynamic economic models).

3.3.2.1 REMI Policy Insight Economic Multipliers with TOPS-BC. Economic Multipliers used in MCIBAS-EIAS approach, which were derived from REMI policy insight for the Indiana Department of Transportation will be employed in the present study with TOPS-BC. REMI policy insight is a pure dynamic economic simulation model, so it leaves space for users

TABLE 3.1
Data Inputs and Default Benefit Calculation of Nontraditional Corridor Improvements (Source: FHWA, 2012)

Operations Strategies	Data Inputs	Default Benefit Calculations
Work Zone Management	Length of Analysis Period Freeway Volume Freeway Number of Lanes Freeway Capacity Freeway Free Flow Speed Freeway Link Length	Travel Time Crashes Travel Time Reliability
Arterial Signal Coordination	Length of Analysis Period Average Volume Number of Lanes Roadway Capacity Free Flow Speed Arterial Link Length Level of Timing Sophistication	Travel Time Crashes Fuel Use
Traffic Incident Management	Length of Analysis Period Average Volume Number of Lanes Roadway Capacity Free Flow Speed Link Length Average Time (minutes) Saved by Travelers Acting on the Information	Travel Time Reliability Fatality Crashes Secondary Crashes (Optional) Fuel Use (Operational)
Access Management	Length of Analysis Period Average Volume Number of Lanes Roadway Capacity Free Flow Speed Crash Modification Factor	Travel Time Crashes
Road Diets	Length of Analysis Period Average Volume Number of Lanes Link Length Roadway Capacity Free Flow Speed Crash Modification Factor	Crashes

TABLE 3.2
Benefits Evaluation of Nontraditional Corridor Improvements

Non-Capacity Corridor Improvements	Travel Time Savings	Travel Time Reliability Savings	Reduction in Crashes	Reduction in Fatal Crashes	Reduction in Secondary Crashes	Fuel Use Savings	Emissions Savings
Arterial Traffic Signal Coordination	Yes	No	Yes	No	No	Yes	×
Traffic Incident Management	No	Yes	No	Yes	Θ	Θ	×
Work Zone Systems	Yes	Yes	Yes	No	No	No	No
Access Management	Yes	No	Yes	Yes	No	No	No
Road Diets	No	No	Yes	Yes	No	No	No

“ × ”: Benefits often associated with this strategy, but not currently included in the benefits calculated by TOPS-BC or TOP-EIA.

“Θ”: optional. Users have the option to enter an impact if data is available to support this strategy impact. The default impact is set to zero.

to estimate business cost savings and business market reach from a transportation investment per their specific situation. This feature is especially important for nontraditional corridor improvements. These strategies are sensitive to where they are deployed for two reasons. One is that the differences in link capacity and speed limit of highways leads to a different estimation of user benefits, and then results in distinguished business costs savings. The other is that most nontraditional corridor improvements are associated with reliability improvement. The accurate estimation of nonrecurring congestion is one of core objectives for nontraditional corridor improvements like Traffic Incident Management. TOPS-BC clearly separates nonrecurring congestion from recurring congestion based on link facility type (e.g., rural freeway, urban freeway, or principle arterial) so it resolves the concern of overestimating or underestimating the reliability benefits to some degree.

It is fairly simple to complete the conversion from selected user benefits to the corresponding economic development impacts through using the MICBAS-EIAS approach economic multipliers. Users first need to use TOPS-BC to calculate the direct business cost savings as shown in Figure 3.1. Next, they should multiply the business cost savings (auto and trucks) separately by the corresponding economic multipliers derived from REMI Policy Insight. The economic development indicators (such as GRP, income, and job) are finally presented for the analysis year and future years.

4. TOOL DESCRIPTION

4.1 Overview

The following sections briefly describe the tool developed to measure the economic development impacts of four corridor improvements as well as a case study search tool for road diets. The tool developed, called TOPS-EIA (Tools for Operations-Economic Impact Analysis), is based on the framework explained in Section 3.2, and builds upon TOPS-BC. Therefore, TOPS-EIA keeps many of the attributes of TOPS-BC such as simplicity and flexibility to adapt calculations and/or parameters. The interface follows the same color-coded cells and functionality structure of TOPS-BC, which has the advantage that the TOPS-BC documentation such as its Desk Reference (FHWA, 2012) and its user manual (FHWA, 2013) are complementary to the present report. Notwithstanding these similarities, TOPS-EIA extends the capabilities of TOPS-BC to allow the measurement of business cost savings over the project time horizon and their consequent economic development impacts (EDI). Additionally, TOPS-EIA incorporates the following modifications or additions to TOPS-BC:

- Updated user interface to streamline the analysis,
- Addition of modal split in the benefits calculations,
- Addition of a help tab for quick reference for the tool inputs and outputs,
- Provision of vehicle miles traveled (VMT) and vehicle hours traveled (VHT) per mode,
- Incorporates non-fuel costs in the benefits calculations, and
- Incorporates a time horizon for the benefits.

The main contribution of TOPS-EIA is that it allows any user who is able to aggregate information on the components mentioned in the framework to evaluate the economic development impacts of the selected corridor improvements at the sketch-level planning process. Users do not need to rely on expensive commercial software packages to complete this task and the tool could be easily updated or tailored to local conditions.

TOPS-EIA is subdivided into 5 modules and the following sections describe each one.

- Section 4.2 describes the tool to measure the EDI of arterial signal coordination (ASC) strategies,
- Section 4.3 describes the traffic incident management (TIM) tool,
- Section 4.4 describes the work zone management (WZM) tool,
- Section 4.5 describes the Access Management (AM) tool, and
- Section 4.6 describes the case search tool for road diets (RD) strategies.

4.2 Arterial Signal Coordination

The arterial signal coordination tool (ASC) was designed to provide an estimate of the benefits of traffic signal improvements that were implemented to make the flow of vehicles more efficient. There are three types of signal improvement that can be analyzed in the tool. These types vary according to the level and complexity of their implementation and include:

- Preset timing
- Actuated corridor systems
- Centrally controlled signal systems

The tool focuses on measuring the business cost savings due to the implementation of these strategies in comparison with a baseline scenario in which the corridor does not include a signal coordination system. Better levels of service in the corridor result in savings for all users, including personal cars and commercial vehicles. The savings in travel time, safety, and vehicle operating costs are annualized and combined with economic multipliers in order to estimate the impacts of the project on gross regional product (GRP), personal income, and employment. Figure 4.1 presents a general overview of the inputs, analysis, and outputs of the tool. Each of the elements shown in Figure 4.1 are explained in the following subsections. A more detailed explanation of most of the inputs can also be found in FHWA (2012).

Input I: Project Information

The first step in running the tool is to enter information related to the timeframe of the project analysis as well as the type of project to be implemented. This information includes the year of analysis ("Current Year"), the year that the project opens or starts operations, and the time horizon for the analysis, which is the expected lifetime of the project. This section also includes the length of the analysis period in hours, which covers the time of the day for the analysis (typically peak-hour periods) and represents the temporal operating parameters of the strategy. This input also establishes the period for which the volume of vehicles and capacity of the facility should be specified. The number of hours for the period of analysis that can be entered is between 1 and 4.

This section of the tool also includes a drop-down menu, where one of the three aforementioned signal coordination strategies is selected. Whenever the period of analysis or the type of facility is modified, the tool will update the default values for the capacity of the corridor ("link-capacity") and free flow speed (FFS). It should be noted that TOPS-EIA does not incorporate information about the construction or operations and maintenance (O&M) of the facility. Therefore, the costs or benefits of these activities are not reflected in the tool.

Input II: Facility Characteristics

The second section of the tool needs information about the corridor segment under analysis. This information includes the length of the segment in miles, the number of lanes, and the link capacity per period. The link capacity should reflect the period of analysis (see Input I) as well as the number of lanes being analyzed. The tool will provide a default value for the corridor capacity, but this value can be overridden.

Additionally, this section will require entering the free flow speed (FFS) of the facility, which could be calculated externally and reflects speed in the absence of congestion. A rule of thumb is to use 5 mph over the posted speed limit. The tool will also provide a default value for FFS, according to default capacities for different facilities (FHWA, 2012).

Finally, the demand (volume of vehicles) is entered into the tool. This value reflects the number of both trucks and cars during the entire period of analysis in all lanes of the facility under analysis.

Input III: Impact Due Strategy

This section of the tool contains information about the expected impacts of the signal coordination system on the performance of the facility. The facility's performance is measured through a set of metrics that include capacity of the facility, average speed,

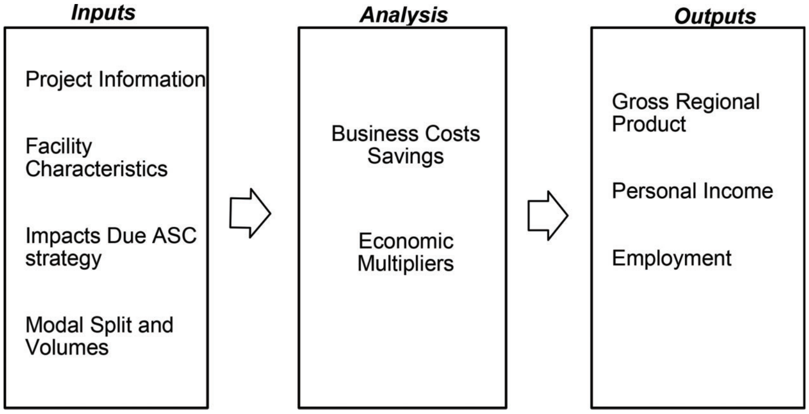


Figure 4.1 General overview of the arterial signal coordination tool.

TABLE 4.1
Expected Impacts for ASC Strategies on Selected Facility Performance Metrics

Metric	Default Impact Values
Capacity of the facility	The capacity of the facility is expected to change by 8% for preset timing strategies, 10% for traffic actuated strategies, and 12% for central control strategies (FHWA, 2012). The capacity is expressed in the number of vehicles in the facility during the period of analysis
Average speed	The change in speed is expected to vary between 8% and 20% for traffic actuated strategies, and between 9% and 16% for central control strategies. Not enough information was found to suggest a range of impacts for preset timing strategies. The unit of analysis is miles per hour (mph)
Crash rate	This percentage will apply to all severities of crashes. A small value is suggested due to the high variability in the range of impacts (FHWA, 2012). Nonetheless, a range of impacts between 2% and 7% is recommended for preset timing. No values are suggested for traffic actuated or central control strategies. Crash rates are expressed as crashes per million VMT
Crash duration	The percent reduction in crash duration could be entered by the user based on local conditions. No range of impacts is recommended
Fuel use	The expected reduction of fuel consumption is 5% for all three signal coordination strategies. Similarly, the expected impacts vary between 6% and 13%

crash rate and crash duration, as well as fuel consumption. The impacts of the strategy on these metrics are expressed as percentage improvements from a base case scenario where no signal coordination strategy exists in the facility.

Additionally, the tool will suggest an expected value of the impacts in each category as well as a range of impacts when data is available. A list of the performance metrics, along with a set of default impact values, is shown in Table 4.1. The range of impacts can be seen in Table C.1 in Appendix C. The default values and range of impacts are based on two main sources:

1. The FHWA Tool for Operations Benefit/Cost (TOPS-BC) tables of impacts (FHWA, 2013), and
2. The benefits database of intelligent transportation systems (ITS) database from the U.S. Department of Transportation (FHWA, n.d.b).

It should be noted that the range of impacts for each ASC strategy might have a significant range of variability because they are based on empirical evidence from projects located in different areas and collected by different agencies. These percentages vary, not only because of factors such as the type of facility, trip volumes, and size of the interventions, but also because of the level of optimization in the implemented strategy. The metrics and expected values are shown in Table 4.1.

Additionally, given that the tool can evaluate the effects of changing the number of lanes in the built scenario, the analyst can enter that change in this section. A change in the number of lanes of the facility will affect its capacity and therefore the calculations that depend on the volume to capacity ratio (such as travel time savings and crash rates).

Input IV: Modal Split and Trip Purpose

The fourth section of the tool shows the modal split between cars and trucks based on traffic volumes of the facility. They are entered as decimals (i.e., 0.10 equivalent to 10%). Similarly, this section shows the trip purpose split for cars in three classes:

1. Commuting: Commuting trips include trips to and from work.
2. Personal: Personal trips include all other purposes.
3. Businesses: Business trip include trips that are work-related (e.g., attend a meeting, provide services).

These values can be taken from the National Household Travel Survey (NHTS) or updated to local conditions. The tool incorporates a set of default values that reflect Indiana regional trends obtained from the Indiana Department of Transportation.

Analysis: Business Costs Savings and Economic Multipliers

Inputs I to IV are used to calculate the facility performance for two scenarios:

- Baseline scenario (i.e., without the signal coordination strategy).
- Built scenario (labeled as "improvement" in the tool). The built scenario incorporates all the impacts due to strategy entered in input III that can be seen in the "facility performance" section of the tool. The tool will calculate the impacts on the performance measures mentioned in section 3.7 according to Table 4.1. Therefore, the tool will calculate travel time savings, safety savings, and vehicle operating costs as primary impacts while travel time reliability benefits are considered a secondary impact.

The business costs are a fraction of the total user benefits corresponding to commercial purposes (i.e., truck trips and auto–business trips, also called on-the-clock trips). These benefits are annualized considering the number of workdays per year (250 by default in the tool) for the initial year of operations (year the project opens) and end year of the time horizon (see input I). Subsequently, the business savings are multiplied by a set of economic multipliers (taken from MCIBAS SEAT) in order to calculate the economic development impacts during the time horizon of the project (see Section 3.7.2). These multipliers were developed using REMI (Regional Economic Models, Inc.) and include gross regional product (GRP), personal income, and employment. The base year for these economic multipliers is 2015. If a different year of analysis is used, the tool will use a set of economic deflators to update the GRP and personal income multipliers (the current set of deflators covers the years 2016 to 2025). The impacts on employment, however, will be reported using the 2015 base multiplier. Additionally, these economic multipliers are for the whole State of Indiana (i.e., state level multipliers) and can be used independently of the region where the project is located. Notwithstanding, it is an advantage to compare the benefits of different projects under the same conditions; however, caution should be exercised when interpreting these results as local effects.

Outputs: Economic Development Impacts

The results of the ASC tool analysis are summarized in three indicators of economic development impacts covering the whole time horizon as a consequence of the implementation of the arterial signal coordination strategy. The economic multipliers are described as follows:

- Gross Regional Product (GRP), as a final demand, represents the sum of the consumption, investments, government expenditure, and exports minus imports (REMI, n.d.b). It is expressed in millions of dollars for the year of analysis (see Input I).
- Personal Income is the income that received by persons including all sources. It represents the sum of wages, salaries, proprietor's income with inventory valuation and capital adjustments, rental income of persons with capital consumption adjustments, personal dividend income, personal interest income, and personal current transfer receipts minus contributions for government social insurance. Personal income is expressed in millions of dollars in the year of analysis and represents the whole time horizon.
- Employment is represented by the estimated number of jobs, full-time plus part-time, by place of work. Both the part-time and full-time jobs are counted equally (i.e., same weight). This indicator doesn't include family or unpaid workers. It is expressed in in job-years (i.e., one job with a duration of one year is equivalent to one job-year). As previously explained, the employment indicator will be calculated using the employment multiplier for the base year (2015).

Table 4.2 presents a summary of the main inputs and outputs of the tool as well as some potential data sources in Indiana.

4.3 Traffic Incident Management

The traffic incident management (TIM) tool was designed to provide an estimate of the benefits of the implementation of incident management strategies. This strategy usually includes the coordination of different sub strategies, such as incident detection and verification, incident response, and freeway service patrols (FSP). TIM strategies have a greater impact on non-recurring delay (incident delay) than on recurring delay and crash rates (excluding secondary crashes) (FHWA, 2012) because it reduces the time required to clear traffic incidents. Therefore, non-recurring delay is the main benefit derived from this tool as it is measured in the travel time reliability section of the tool.

Similar to ASC strategies, the tool focuses on measuring the business cost savings due to the implementation of this strategy in comparison with a baseline scenario where the corridor does not include a traffic management system. The savings in travel time reliability, travel time, safety, and vehicle operating costs are annualized and combined with economic multipliers to estimate the impacts of the project on gross regional product (GRP), personal income, and employment. Figure 4.2 presents a general overview of the inputs, analysis, and outputs of the tool. Each of the elements shown in Figure 4.2 is explained in the following subsections. A more detailed explanation of most of the inputs can also be found in FHWA (2012). Similarly, a more in-depth explanation of TIM strategies and its benefits can be found in FHWA (n.d.c).

Input I: Project Information

The first step to run the tool is to enter information related to the timeframe of the project analysis as well as the type of project to be implemented. This information includes the year of analysis ("Current Year"),

TABLE 4.2
Summary of the Primary Data and Sources for the ASC Tool

Data Inputs	Data Source
Length of Analysis Period	Project description provided by the state DOT or other agencies
Average Volume	ISTDM or data retrieved from a Traffic-Count Database System such as from Modern Traffic Analytics (MS2)—indot.ms2soft.coma
Number of Lanes	Project description provided by the state DOT or other agencies
Roadway Capacity	ISTDM or default calculations can be used
Free Flow Speed	ISTDM or default calculations can be used
Arterial Link Length	Project description provided by the state DOT or other agencies
Level of Signal Timing Sophistication	Project description provided by the state DOT or other agencies

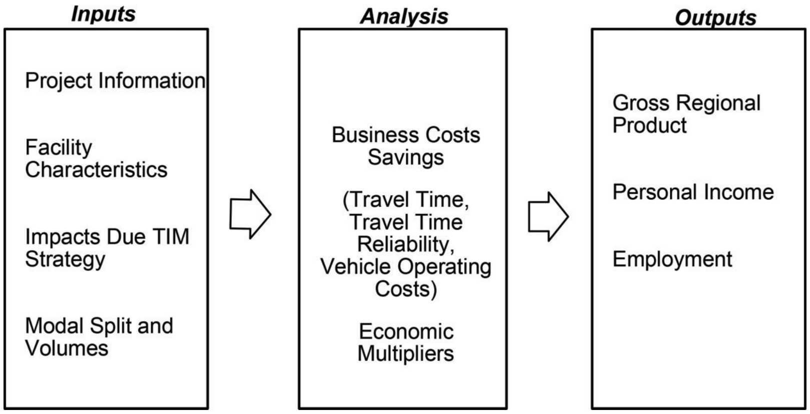


Figure 4.2 General overview of the traffic incident management tool.

the year that the project opens or starts operations, and the time horizon for the analysis, which is the expected lifetime of the project. This section also includes the length of the analysis period in hours, which covers the time of day for the analysis (typically peak-hour periods) and represents the temporal operating parameters of the strategy. This input also establishes the period for which the volume of vehicles and capacity of the facility should be specified. The number of hours for the period of analysis is between 1 and 4. It should be noted that TOPS-EIA does not incorporate information about the construction or operations and maintenance (O&M) of the facility or vehicles used in the TIM system. Therefore, the costs or benefits of these activities are not reflected in the tool. Additional information about the costs of these systems can be found in TOPS-BC and the Desk Reference (FHWA, 2012).

Input II: Facility Characteristics

The second section of the TIM tool requires entering information about the corridor segment under analysis. This information includes the length of the segment in miles, the number of lanes, and the link capacity per period. The link capacity should reflect the period of analysis (see Input I) as well as the number of lanes under analysis. The tool will provide default values for the capacity of the corridor that can, however, be overridden. This section will also require entering the free flow speed (FFS) of the facility, which could be calculated externally and reflects speed in the absence of congestion. The tool will also provide a default value for FFS, according to default capacities for different facilities. A rule of thumb is to use 5 mph over the posted speed limit (FHWA, 2012). Finally, the demand (volume of vehicles) is entered in the tool. This value reflects the number of both trucks and cars during the entire period of analysis in all lanes of the facility.

Input III: Impact Due Strategy

This section of the tool contains information about the expected impacts of the traffic incident management system on the performance of the facility. The description of the available inputs is similar to the ASC strategy; however, the expected impacts on the facility performance are different. A list of the performance metrics, along with a set of default impact values provided in the tool, is shown in Table 4.3. The range of impacts can be seen in Table C.2 in Appendix C. The default values and range of impacts are based on three main sources: (a) the FHWA Tool for Operations Benefit/Cost (TOPS-BC) tables of impacts (FHWA, 2013), and (b) the benefits database of intelligent transportation systems (ITS) database from the U.S. Department of Transportation (FHWA, n.d.b).

It should be noted that the range of impacts for the TIM strategy might have a significant range of variability, because they are based on empirical evidence from different sub-strategies and projects located in different areas. These percentages vary, not only because of factors such as the type of facility, trip volumes, size of the interventions, but also because of the type of TIM strategy implemented. The metrics and expected values are shown in Table 4.3.

Similar to the other tools, the analyst can modify the number of lanes in the built scenario by entering a value in the “change in the number of lanes” cells. This change will affect the capacity and therefore the calculations that depend on the volume-to-capacity ratio (such as travel time savings and crash rates).

Input IV: Modal Split and Trip Purpose

The fourth section of the tool shows the modal split between cars and trucks, based on traffic volumes of the facility. The description is identical to Input IV of arterial signal coordination strategies.

Analysis: Business Costs Savings and Economic Multipliers

Inputs I to IV are used to calculate the facility performance for a baseline scenario (i.e., without the traffic incident management strategy) and a built scenario (labeled as “improvement” in the tool). The built scenario incorporates all the impacts due to the strategy explained

TABLE 4.3
Expected Impacts for TIM Strategies on Selected Facility Performance Metrics

Metric	Impact
Average speed	TIM strategies will have an expected impact that range between 8% and 20% increase in the average speed. However, no default values are suggested in the tool.
Crash rate	This percentage reduction will apply to all severity crashes and is expected to vary between 15% and 50%. Nonetheless, no specific default value is suggested
Crash duration	This constitutes the most important benefit of TIM's implementation. It is expected that the duration of incidents will be reduced by 40%. However, empirical evidence suggest this could be up to 60%
Percent time device is disseminating information; Percent drivers using information; Minutes saved by drivers	These values are entered if an advance traveler information system (ATIS) is implemented as part of the TIM strategy. They will affect the travel time reliability in the corridor as a function of the average amount of time saved by travelers that *access* and *act* on the information provided by these systems. The time saved, therefore, also depends on the percent of time that the system is disseminating information. No default values are suggested for this inputs. Additional information can be found in similar "en-route" traveler information strategies such as dynamic message signs and highway advisory radio strategies (see FHWA, 2013)

in input III, the results for which can be seen in the "facility performance" section of the tool. The tool will calculate the impacts on the performance measures mentioned in Section 3.1.1 according to Table 4.3. Therefore, the tool will calculate travel time reliability benefits as primary impacts. The explanation of the business cost savings is similar to that for arterial signal coordination (analysis section).

Outputs: Economic Development Impacts

The results of the tool analysis are a set of three metrics of economic development impacts covering the whole time horizon as a consequence of the implementation of the traffic incident management system. The indicators of economic development are described as follows:

- Gross Regional Product, as a final demand, represents the sum of the consumption, investments, government expenditure, and exports minus imports (REMI, n.d.b). It is expressed in millions of dollars for the year of analysis (see input I).
- Personal Income is the income that is received by persons from all sources. It represents the sum of wages, salaries, proprietor's income with inventory valuation and capital adjustments, rental income of persons with capital consumption adjustments, personal dividend income, personal interest income, and personal current transfer receipts minus contributions for government social insurance. Personal income is expressed in millions of dollars in the year of analysis.
- Employment is represented by the estimated number of jobs, full-time plus part-time, by place of work. Both the part-time and full-time jobs are counted equally (i.e., same weight). This indicator doesn't include family or unpaid workers. It is expressed in job-years (i.e., one job with a duration of one year is equivalent to one job-year). As previously explained, this indicator will be calculated using the employment multiplier for the base year (2015).

Table 4.4 presents a summary of the main input and outputs of the tool, as well as some potential data sources of information in Indiana.

4.4 Work Zone Management

The work zone management (WZM) tool aims to measure the economic development impacts of the implementation of work zone systems. These strategies are implemented with the objective to reduce congestion and delay while improving safety in construction and maintenance zones. This strategy usually includes the coordination of different subsystems or components such as pre-trip information strategies (e.g., Indiana's 511 system), "enroute" information systems (e.g., dynamic message signs), and construction-specific measures such as alternative construction hours (FHWA, 2012). For additional information about WZM systems and their implementation, the reader can refer to FHWA (2012) and FHWA (n.d.d). The main benefits of these systems include restoring and smoothing the traffic by reducing the stop-and-go conditions (FHWA, 2013) that affect travel time, travel time reliability, and safety as primary impacts.

Similar to ASC and TIM strategies, the tool focuses on measuring the business cost savings due to the implementation of this strategy in comparisons with a baseline scenario, where the corridor does not include a work zone management system. The savings in travel time, travel time reliability, and safety are annualized and combined with economic multipliers to estimate the impacts of the project on gross regional product (GRP), personal income, and employment. Figure 4.3 presents a general overview of the inputs, analysis, and outputs of the tool. Each of the elements shown in Figure 4.3 are explained in the following subsections. A more detailed explanation of most of the inputs can also be found in FHWA (2012).

TABLE 4.4
Summary of the Primary Data and Sources for the TIM Tool

Data Inputs	Data Source
Length of Analysis Period	Project description provided by the state DOT or other agencies
Average Volume	ISTDM or data retrieved from a Traffic-Count Database System such as from Modern Traffic Analytics (MS2)—indot.ms2soft.com[a]
Number of Lanes	Project description provided by the state DOT or other agencies
Roadway Capacity	ISTDM or default calculations can be used
Free Flow Speed	ISTDM or default calculations can be used
Link Length	Project description provided by the state DOT or other agencies
ATIS inputs	Project description provided by the state DOT or other agencies

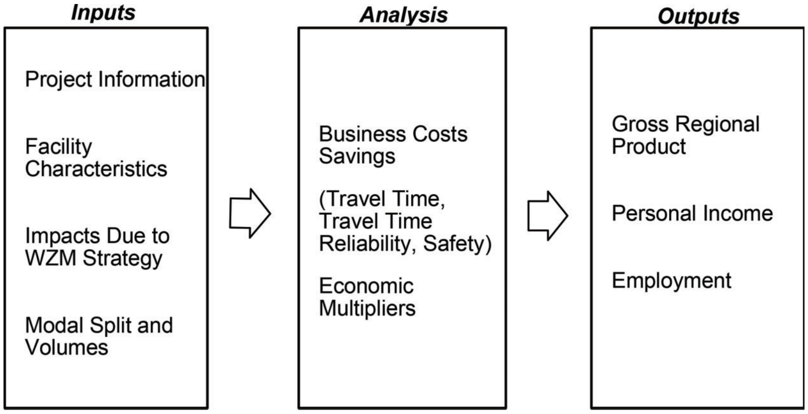


Figure 4.3 General overview of the traffic work zone management tool.

Input I: Project Information

The first step to run the tool is to enter information related to the timeframe of the project analysis as well as the type of project to be implemented. This information includes the year of analysis ("Current Year"), the year that the project opens or starts operations, and the time horizon for the analysis, which is the expected lifetime of the project. This section also includes the length of the analysis period in hours, which covers the time of day for the analysis (typically peak-hour periods) and represents the temporal operating parameters of the strategy. This input also establishes the period for which the volume of vehicles and capacity of the facility should be specified. The number of hours for the period of analysis is between 1 and 4. It should be noted that TOPS-EIA does not incorporate information about the construction or operations and maintenance (O&M) of the facility equipment used in the WZM system. Therefore, the costs or benefits of these activities are not reflected in the tool. Additional information about the costs of these systems can be found in TOPS-BC and the associated Desk Reference (FHWA, 2012).

Input II: Facility Characteristics

The second section of the WZM tool requires entering information about the corridor segment under analysis. This information includes the length of the segment in miles, the number of lanes, and the link capacity per period. The link capacity should reflect the period of analysis (see Input I) as well as the number of lanes under analysis. The tool will provide default input values for the link capacity that could be overridden. Additionally, this section will require entering the free flow speed (FFS) of the facility, which could be calculated externally and reflects the speed in absence of congestion. The tool will also provide a default value for FFS mapped according to default capacities for different facilities. Additionally, a rule of thumb is to use 5 mph over the posted speed limit (FHWA, 2012). Finally, the demand (volume of vehicles) is entered into the tool. This value reflects the number of both trucks and cars during the entire period of analysis on all lanes of the facility.

Input III: Impact Due Strategy

This section of the tool contains information about the expected impacts of the work zone management system on the performance of the facility. The description of the available inputs is similar to the ASC and TIM strategies; however, the expected impacts on the facility performance are different. A list of the performance metrics along with a set of default impact values provided in the tool is shown in Table 4.5 and the range of impacts can be seen in Table C.3 in Appendix C.

TABLE 4.5
Expected Impacts for TIM Strategies on Selected Facility Performance Metrics

Metric	Impact
Average speed	WZM strategies will have an expected speed increase of 5%. According to the literature, this increase could be up to 9% or 15%
Crash rate	There is an expected reduction of 5%. This value is very conservative, because different strategies could deliver up to 40% reduction in crash rates
Crash duration	A reduction of 10% is expected, but this value could be up to 45%
Percent time device is disseminating information; Percent drivers using information; Minutes saved by drivers	These values are entered if an advance traveler information system (ATIS) is implemented as part of the WZM strategy. They will affect the travel time reliability in the corridor as a function of the average amount of time saved by travelers that *access* and *act* on the information provided by these systems. It, therefore, also depends on the percent of time that the system is disseminating information. No default values are suggested for these inputs. Additional information can be found in similar "en-route" traveler information strategies such as dynamic message signs and highway advisory radio strategies (see FHWA, 2013)

The default values and range of impacts are based on three sources:

1. The FHWA Tool for Operations Benefit/Cost (TOPS-BC) tables of impacts (FHWA, 2013),
2. The benefits database of intelligent transportation systems (ITS) database from the U.S. Department of Transportation (FHWA, n.d.b), and
3. The Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2016/15 (Ukkusuri, Gkritza, Qian, & Sadri, 2016).

Similar to the ASC and TIM tools, the WZM strategy might have a significant range of variability, because it could be based on different sub strategies and projects located in different areas. These percentages vary not only because of factors such as the type of facility, trip volumes, and size of the interventions, but also, because of the type of WZM strategy implemented. The metrics and expected values are shown in Table 4.5.

As with the other tools, the analyst can modify the number of lanes in the built scenario by entering a value in the "change in the number of lanes" cells. This change will affect the capacity and therefore the calculations that depend on the volume to capacity ratio (such as travel time savings and crash rates).

Input IV: Modal Split and Trip Purpose

The fourth section of the tool shows the modal split between cars and trucks based on traffic volumes on the facility. The description is identical to Input IV for the ASC and TIM strategies.

Analysis: Business Cost Savings and Economic Multipliers

Inputs I to IV are used to calculate the facility performance for a baseline scenario (i.e., without the traffic incident management strategy) and a built scenario (labeled as "improvement" in the tool). The built scenario incorporates all the impacts due to the strategy explained in the Input III subtitle, whose results can be seen in the "facility performance" section of the tool. The tool will calculate the impacts for the performance measures mentioned in Section 3.1.1 according to Table 4.5. Therefore, the tool will calculate travel time, travel time reliability, and safety benefits as primary impacts. The explanation of the business cost savings is similar to the ASC and TIM strategies.

Outputs: Economic Development Impacts

The results of the tool analysis are a set of three metrics for economic development impacts covering the whole time horizon as a consequence of the implementation of the work zone management system. The indicators of economic development are described as follows:

- Gross Regional Product, as a final demand, represents the sum of the consumption, investments, government expenditure, and exports minus imports. It is expressed in millions of dollars for the year of analysis (see Input I).
- Personal Income, the income received by persons, including all sources. It represents the sum of wages, salaries, proprietor's income with inventory valuation and capital adjustments, rental income of persons with capital consumption adjustments, personal dividend income, personal interest income, and personal current transfer receipts, minus contributions for government social insurance. Personal income is expressed in millions of dollars in the year of analysis and represents the whole time horizon.
- Employment is represented by the estimated number of jobs, full-time plus part-time, by place of work. Both part-time and full-time jobs are counted equally (i.e., same weight). This indicator doesn't include family or unpaid workers. It is expressed in in job-years (i.e., one job with a duration of one year is equivalent to one job-year). As previously explained, this indicator will be calculated using the employment multiplier for the base year (2015).

Table 4.6 presents a summary of the main inputs and outputs of the tool as well as some potential data sources of information in Indiana.

4.5 Access Management

The access management (AM) tool was built to measure the economic development impacts of the

TABLE 4.6
Summary of the Primary Data and Sources for the WZM Tool

Data Inputs	Data Source
Length of Analysis Period	Project description provided by the state DOT or other agencies
Average Volume	ISTDM data or data retrieved from a Traffic-Count Database System such as from Modern Traffic Analytics (MS2)—indot.ms2soft.com[a]
Number of Lanes	Project description provided by the state DOT or other agencies
Roadway Capacity	ISTDM data or default calculations can be used
Free Flow Speed	ISTDM data or default calculations can be used
Link Length	Project description provided by the state DOT or other agencies
ATIS inputs	Project description provided by the state DOT or other agencies

Policy-related measures	Physical measures

• Zoning Subdivision Regulations (Land Use Restrictions)
• Access Codes/Spacing (Restriction on Driveways)
• Purchase of Access Rights
• Establishment of Setbacks from Interchanges and Intersections
	• Access Spacing
	  • Signal Spacing
	  • Driveway Spacing
	• Median Treatments
	  • Two-way Left turn
	  • Raised Median
	• Turning Lanes
	  • Left Turns
	  • Indirect Turns
	  • Right Turns
	  • Roundabouts

Figure 4.4 Access management strategies. (Adapted from Gluck et al., 1999.)

implementation of a subset of strategies in access management. AM strategies aim to create a balance between two competing needs in the transportation system: land accessibility and traffic movement (Gluck & Lorenz, 2009). AM is formally defined as "the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway. It also involves roadway design applications, such as median treatments and auxiliary lanes, and the appropriate spacing of traffic signals […]" (TRB, 2003 as cited in the INDOT Access Management Guide [Gluck & Lorenz, 2006]). Therefore, AM can be seen as the process where the agency implements a set of measures to preserve or improve the efficiency of the system in terms of safety, capacity, speed, and time reliability while, at the same time, provides adequate levels of accessibility to adjacent neighborhoods and businesses. These measures cover a wide range of policies (such as land use restrictions) and/or physical interventions (such as raised medians). More than a hundred techniques could be identified (Gluck, Levinson, & Stover, 1999) that could be grouped in categories such as those shown in Figure 4.4. Nonetheless, Figure 4.4 does not present an exhaustive list of all the categories of AM strategies. Other classifications could include, for example, driveways, neighborhood streets, and policy-oriented measures (CUTR, 1998 & Dixon, Yi, & Brown, 2012, as cited in TDM, 2014; see Figure C.1 in Appendix C).

The AM tool focuses on three main categories that best fit the current needs of INDOT, as identified in a survey of the advisory committee members. These strategies include:

- Median treatments
  - Installation of two-way two left-turn lanes (TWLTL)
  - Raised medians
- Signalization spacing

The importance of the AM tool is that it provides an estimate of the statewide economic impacts of these three strategies, which could inform the agency and stakeholders about the benefits of these strategies. The tool could be particularly important in facing two important challenges regarding AM implementations: opposition of business owners in abutting areas and institutional resistance to try new approaches such as AM (TDM, 2014). A more detailed explanation of the types, concepts, and implementation of access management strategies can be found in the NCHRP Report 420 (Gluck et al., 1999), the INDOT Access Management Guide (Gluck & Lorenz, 2009), and FHWA (n.d.a).

The main benefits derived from AM strategies are in terms of safety and capacity improvements. The tool translates these benefits to business cost savings, taking into account a baseline scenario where the corridor does not include any access management strategy.

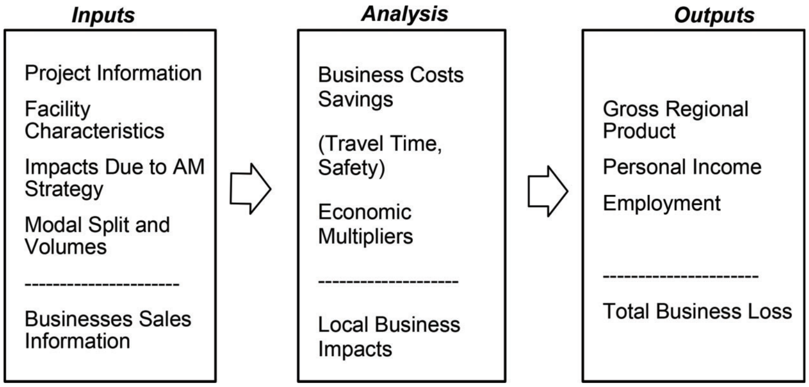


Figure 4.5 General overview of the access management tool.

The savings in travel time, travel time reliability, and safety are annualized and combined with economic multipliers to estimate the impacts of the project on gross regional product (GRP), personal income, and employment.

Figure 4.5 presents a general overview of the inputs, analysis, and outputs of the tool. Each of the elements shown in Figure 4.5 is explained in the following subsections.

Input I: Project Information

The first step in running the tool is to enter information related to the timeframe of the project analysis as well as the type of project to be implemented. This information includes the year of analysis ("Current Year"), the year that the project opens or starts operations, and the time horizon for the analysis, which is the expected lifetime of the project. This section also includes the length of the analysis period in hours, which covers the time of day for the analysis (typically peak-hour periods) and represents the temporal operating parameters of the strategy. This input also establishes the period for which the volume of vehicles and capacity of the facility should be specified. The number of hours for the analysis period is between 1 and 4. It should be noted that TOPS-EIA does not incorporate information about the construction or operations and maintenance (O&M) of the access management infrastructure. Therefore, the costs or benefits of these activities are not reflected in the tool. Additional information and sources for cost estimation can be found in Gluck et al. (1999).

Input II: Facility Characteristics

The second section of the AM tool requires entering information about the corridor segment under analysis. This information includes the length of the segment in miles, the number of lanes, and the link capacity per period. The link capacity should reflect the period of analysis (see Input I) as well as the number of lanes under analysis. The tool will provide default input values for the link capacity that could be overridden. Additionally, this section will require entering the free flow speed (FFS) of the facility, which could be calculated externally and reflects the speed in the absence of congestion. The tool will also provide a default value for FFS determined according to default capacities for different facilities. A rule of thumb is to use 5 mph over the posted speed limit (FHWA, 2012). Finally, the demand (volume of vehicles) is entered into the tool. This value reflects the number of both trucks and cars during the entire period of analysis on all lanes of the facility.

Input III: Impact Due Strategy

This section of the tool contains information about the expected impacts of the access management strategy on the performance of the facility. The description of the available inputs is similar to the WZM and TIM strategies; however, the expected impacts on the facility performance are different. A list of the performance metrics, along with a set of default impact values provided in the tool, is shown in Table 4.7 and the range of impacts can be seen in Table C.4 in Appendix C.

The default values and range of impacts are based on two sources: a) Crash modification factors (CMF) Clearinghouse (2010) and b) the NCHRP Report 420 (Gluck et al., 1999). Similar to previous strategies, the AM strategy might have significant variability because it could be based on different corridor characteristics (e.g., density of signalized intersections) or projects located in areas with different land uses (e.g., commercial versus residential).

A more disaggregated overview of the different impacts for three selected strategies can be found in the access management impacts tab called "AM_Impacts." A summary of these metrics and expected values are shown in Table 4.7. Additionally, when "Signalization spacing" is selected, the user should enter an additional input called "Reduction in the Number of Signals per Mile." This input is used to calculate the changes in the average speed of vehicles in the corridor. Similarly, the default value for the reduction in crash rate will be calculated using the initial and built-scenario signal spacing. This calculation is based on Mauga & Kaseko

TABLE 4.7
Expected Impacts for Selected AM Strategies on Facility Performance Metrics

Metric	**Default Impact Values**
Capacity of the facility	The capacity of the facility is expected to increase by 30% for both median treatments (including two-way left turn lanes (TWLTL) and non-traversable medians) and signal spacing projects. The units of capacity are expressed as the number of vehicles during the period of analysis
Average speed	The speed is expected to increase between 9% and 39% for signalization spacing projects with respect to a baseline scenario where the corridor has 2 traffic signals per mile. Therefore, this default value will vary as a function of the resulting number of signals per mile in the built scenario. No range of impacts is recommended for median treatments
Crash rate	This percentage will apply to all severities of crashes. The default value in crash rate reduction due to signalization spacing strategies will vary according to the initial and final spacing between signals, as shown in Equation 4.1. No range of impacts is recommended for this strategy For median treatments, the default values for crash rate reduction are 23% for two-way left turn lane (TWLT) and 38% for non-traversable medians. The range of these values varies between 11% and 34% for TWLT strategies and between 17% and 67% for non-traversable median strategies. A more detailed range of impacts is provided in Table C.4 in Appendix C, which could also be found in the tab "AM impacts "of the tool. Crash rates are expressed as crashes per million VM
Crash duration; Fuel use	The percent reduction in crash duration and fuel use could be entered by the user based on local conditions. No range of impacts or default values is recommended

(as cited in record 2454 of the CMF Clearinghouse, 2010), and shown in Equation 4.1.

$$e^{-0.1276*(Y-X)} \tag{4.1}$$

where X is the base scenario spacing and Y is the spacing with the project. For example, a reduction of the number of signals from 4 to 2 will lead to an increase of 9% in the crash rates.

As with the other tools, the analyst can modify the number of lanes in the built scenario by entering a value in the "change in the number of lanes" cells. This change will affect the capacity and therefore the calculations that depend on the volume to capacity ratio (such as travel time savings and crash rates).

The AM tool also includes a section where the expected economic impacts of implementing raised medians and allowing right-turns only, on local business can be estimated. This section of the tool measures the possible adverse impacts on adjacent businesses resulting from restricting left-turns. The calculations are based on an adapted version of the framework proposed in the NCHRP 420 Report (Gluck et al., 1999), as well as data from the ITE Trip Generation Manual (9th ed.) and the 2012 U.S. Economic Census. The economic impacts depend on the size and type of economic activity of the abutting area, the business dependability on pass-by traffic, as well as the businesses' demand represented by the number of vehicles and the average purchase per vehicle. The main inputs for this section of the tool are shown in Table 4.8.

Input IV: Modal Split and Trip Purpose

The fourth section of the tool shows the modal split between cars and trucks based on traffic volumes on the facility. The description is identical to Input IV for the ASC and TIM strategies.

Analysis I: Business Cost Savings and Economic Multipliers

Inputs I to IV are used to calculate the facility performance for a baseline scenario (i.e., when no access management strategies are implemented) and a built scenario (labeled as "improvement" in the tool). The built scenario incorporates all the impacts due to the strategy explained in the Input III subtitle, whose results can be seen in the "facility performance" section of the tool. The tool will calculate the impacts for the performance measures mentioned in Section 3.1.1 according to Table 4.8. Therefore, the tool will calculate travel time, travel time reliability, and safety benefits as primary impacts. The explanation of the business cost savings is similar to the ASC and TIM strategies.

Analysis II: Local Business Impacts

The total loss in business revenue is equivalent to the sum of losses from individual businesses in the affected area. This analysis is only available for non-traversable median (raised median) treatments and is represented by Equation 4.2 (Gluck et al., 1999):

$$Total\ Loss = \sum_{1}^{M} N_i * T_i * P_i * D_i \tag{4.2}$$

where N_i is the is number of establishments in category i where left turn entrance is denied, T_i is the average number of trip ends at establishments of category i

TABLE 4.8
AM Tool Primary Inputs

Input	Description
Number of Businesses	Number of establishments where left turn entrance in denied as a consequence of the raised median project
Entering Trips (Average Peak Hour)	Volume of vehicles entering the facility (i.e., establishment) type during an average peak hour period. This value can be estimated based on field observations or percent estimations from other studies. Table D.1 in Appendix D presents suggested values for this input as a function of the average Gross Floor Area (GFA) of each establishment, or average peak hour volume in the adjacent corridor (for *gasoline service stations with convenience store* and *fast food restaurants with drive through window* categories only). Trips entering the establishments are assumed to be 50% of trip ends
Proportion of trips that represent pass-by trips	Percentage of pass-by traffic at a given location. Table D.2 in Appendix D provides a set of default values based on the land use category of the abutting area
Average dollar purchase	Average dollar in sales purchases per vehicle. Table D.3 in Appendix D provides a set of approximate values based on average annual sales per type of establishment in Indiana taken from the 2012 U.S. Economic Census

during an average peak hour, P_i is the percentage of pass-by vehicles for category i, D_i is the average dollar purchase for category i, and M is number of business categories considered. The application of Equation 4.2 and Tables D.1 to D.3 of the Appendices is demonstrated in the following examples:

- A raised median is implemented in a corridor where a high-turn over restaurant is located. Assuming that the average GFA of 7,000 sq. ft., the number of vehicles entering the facility is 36 veh./hour (i.e., 72.3 trip ends). Similarly, assuming that 43% of these vehicles are pass-by trips, and an average dollar purchase of $7.90 per vehicle, the peak-hour loss in traffic would be $36\frac{veh}{hour}*43\%={}^{15.5\text{veh}}/_{hour}$ and the peak-hour loss will be $15.50\frac{veh}{hour}*{}^{\$7.90}/_{veh}={}^{\$123}/_{hour}$

Outputs: Economic Development Impacts

The results of the tool analysis are a set of three metrics for economic development impacts covering the whole time horizon as a consequence of the implementation of the work zone management system. The indicators of economic development are described as follows:

- Gross Regional Product, as a final demand, represents the sum of the consumption, investments, government expenditure, and exports minus imports (REMI, n.d.b). It is expressed in millions of dollars for the year of analysis (see Input I).
- Personal Income, the income received by persons, including all sources. It represents the sum of wages, salaries, proprietor's income with inventory valuation and capital adjustments, rental income of persons with capital consumption adjustments, personal dividend income, personal interest income, and personal current transfer receipts, minus contributions for government social insurance. Personal income is expressed in millions of dollars in the year of analysis and represents the whole time horizon.
- Employment is represented by the estimated number of jobs, full-time plus part-time, by place of work. Both part-time and full-time jobs are counted equally (i.e., same weight). This indicator doesn't include family or unpaid workers. It is expressed in in job-years (i.e., one job with a duration of one year is equivalent to one job-year). As previously explained, this indicator will be calculated using the employment multiplier for the base year (2015).

Finally, the last section of the tool presents the estimated economic impacts of non-traversable medians strategies on abutting local businesses. This daily estimates could be annualized if information about annual purchases per vehicle are available. Note that the results of this analysis should not be combined with the results of the economic development impact analysis (described in a previous section) to avoid double-counting.

Table 4.9 presents a summary of the main inputs and outputs of the tool as well as some potential data sources of information in Indiana.

4.6 Road Diet Case Search Tool

Road diet strategies consist of removing vehicle lanes from a roadway in order to accommodate extra space for other modes of travel (i.e., pedestrians, cyclists, buses), parking, turn lanes, medians or pedestrian refuge islands (FHWA, 2015). These strategies are typically implemented in corridors with vehicle below 25,000 vehicles per day, and include a number of different configurations or conversions; however, the most common technique is converting 4-lane-2-way undivided corridors into a 3-lane corridor with two through lanes and one two-way left-turn (TWLT) lane.

The road diet (RD) tool aims to provide information about the expected impacts of different sub-strategies according to contextual conditions such as volume of vehicles, land use, and location of the

TABLE 4.9
Summary of the Primary Data and Sources for the AM Tool

Data Inputs	Data Source
Length of Analysis Period	Project description provided by the state DOT or other agencies
Average Volume	ISTDM data or data retrieved from a Traffic-Count Database System such as from Modern Traffic Analytics (MS2).
Number of Lanes	Project description provided by the state DOT or other agencies
Roadway Capacity	ISTDM data or default calculations can be used
Free Flow Speed	ISTDM data or default calculations can be used
Link Length	Project description provided by the state DOT or other agencies
Number of Signalized Intersections per Mile	Project description provided by the state DOT or other agencies

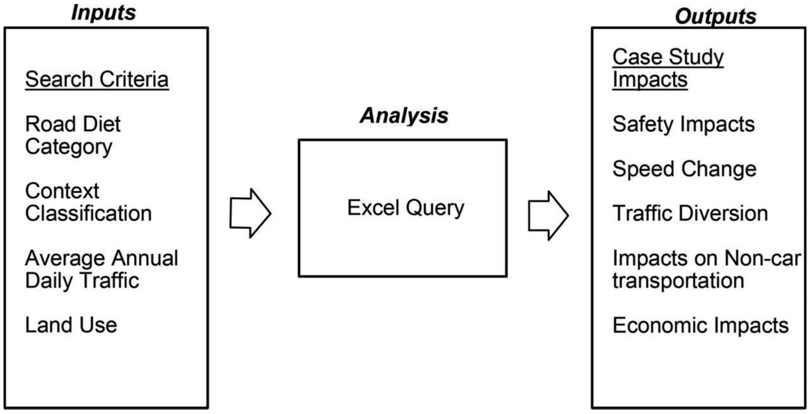


Figure 4.6 General overview of the road diet case search tool.

project. It is based on a database of 60 case studies where the impacts on safety, speed, traffic diversion, changes in capacity, and economic impacts were reported in the literature. As shown in Section 3.7, the main benefit of RD projects is safety, which is the most documented impact. The case studies' impacts are not typically available in all categories and they could be either quantitative or qualitative. Therefore, caution should be taken when interpreting the outputs because they could be highly dependent on the local conditions of each particular case study. Figure 4.6 presents a general overview of the inputs, analysis, and outputs of the tool. Each of the elements shown in Figure 4.6 are explained in the following subsections.

Input I: Road Diet Category

The first step to run the tool is to select the search criteria to filter the case studies. The analyst has the option to choose one specific criterion or use all of them. The first criterion is "road diet category" which corresponds to the general type of RD strategy that was implemented. This search criterion covers the following categories:

- 4-lane to 2-lane conversion
- 4-lane to 3-lane conversion
- 5-lane to 3-lane conversion

Input II: Context Classification

The second criterion in the RD tool describes the context of the project or area where the project was implemented. This search criterion covers the following categories:

- Suburban
- Suburban/Rural
- Urban

Input III: Average Annual Daily Traffic

This criterion describes the range of vehicle volumes in the corridor. The units are in vehicles per day and the database reflects either the average or the maximum number vehicles per day reported. The range of volumes presented below was set according to the frequency of volumes found in the literature.

- Below 10,000 vehicles per day (vpd)
- Between 10,000 and 15,000 vpd
- Between 15,000 and 25,000 vpd

Input IV: Land Use

This input requires selecting a land use type from a list of six general categories that were created according to the case studies. If the land use type was not specified in the case study report, the category was based on investigating the corridor using resources such as

Google Street Maps. However, it should be noted the land uses may have changed over time. Additionally, these land use categories are not specific or detailed as, for example, land uses from Anderson et al. (1976). This search criterion covers the following categories:

- Commercial
- Residential
- Recreational
- Mix
- Schools/University
- Governmental

Analysis: Queries Generation

Inputs I to IV are used to generate a series of queries that are used to filter the case studies and present a summarized version of the case studies that match the criterion or criteria selected. The queries were developed using Visual Basic for Applications (Vba) in Microsoft Excel. A commented copy of the algorithm can be found in Appendix E of this report.

Analysis: Outputs

The outputs of this tool will show a number of case studies that match the search criteria with their corresponding impacts. These impacts include the following categories:

- Safety impacts
- Speed changes
- Reduction in speeders or aggressive drivers
- Traffic diversion
- Changes in non-car transportation
- Changes in capacity
- Economic development impacts

It should be noted that the reported impacts rely on the available literature for each case study; therefore, not all impact categories are reported for each case study.

An overview of the tool sections, inputs, and outputs can be found in Appendix F of this report.

4.7 Summary

This chapter presented an overview of the main characteristics of TOPS-EIA as well as the main inputs and outputs of the tool. The tool inherited the main advantages of its predecessor TOPS-BC and extended its capabilities to measure the economic development impacts of corridor improvements. Four strategies are described, including arterial signal coordination strategies, traffic incident management, work zone management, and access management. This section highlighted that each strategy will have different impacts on the facility performance, which are capture based on empirical data available. In addition to TOPS-EIA, this section also presented an overview of a case search tool to explore the impacts of road diets strategies, which is also based on data from existing case studies. The following section provides an overview of the application of TOPS-EIA to two case studies.

5. CASE STUDIES

5.1 Overview

This chapter presents the application of the arterial signal coordination (ASC) tool in two case studies. The objective of this chapter is twofold; first, to demonstrate the main inputs and outputs of the tool and, second, to validate the results of the ASC tool by comparing them with case studies conducted with similar tools or methodologies. The selection of the case studies was based on the following criteria:

1. Data on the project before the strategy implementation as well as the range of impacts of the deployment needs to be available. This is because TOPS-EIA calculates the highway standard user benefits based on percentage changes on key performance metrics (e.g., speeds) that are reflected with the strategy.
2. The results should be comparable for the selected analysis period. TOPS-EIA calculates the benefits for the period of analysis first, and then converts it to daily and annual benefits.

Two arterial signal coordination case studies are presented in this chapter. The first case study is located in Palm Beach, Florida as reported by Cambridge Systematics (2014). The second case study, located in Hamilton County, Indiana was reported in Lavrenz et al. (2016). Both Cambridge Systematics (2014) and Lavrenz et al. (2016) are the main sources of the inputs for these applications in TOPS-EIA. Dollar values are nominal otherwise noted.

5.2 Case Study 1: Palm Beach Living Lab Analysis (Florida DOT)

5.2.1 Project Description

The data for the analysis was extracted from the "Palm Beach County Living Laboratory Arterial Management System" case study conducted by the Florida DOT using TOPS-BC. The Florida DOT District 4 in collaboration with Palm Beach County Traffic Engineering Department (PBC TED) initiated the "Living Lab" pilot project in 2012 to actively monitor, manage, and improve arterial operations along three major east-west corridors—Okeechobee Blvd., Belvedere Rd., and Southern Blvd. between SR 7 and I-95.

As part of this initiative, FDOT District 4 installed 38 closed-circuit television (CCTV) cameras and 30 BlueTOADs vehicle detection devices along these corridors, and started to monitor traffic conditions and collect travel times in real-time. In addition, FDOT District 4 provided staffing resources at the Palm Beach County Traffic Management Center to monitor real-time traffic conditions, detect incidents, and support Palm Beach County Signal Timing staff in implementing real-time signal timing changes to improve traffic flow and reduce motorist delay. The total length of the project is 33 miles, which includes 76 signals. However, only one segment corresponding to Okeechobee Blvd corridor was considered for this analysis. Figure 5.1 shows the location of the Okeechobee Blvd., Belvedere Rd., and Southern Blvd. between SR 7 and I-95.

The main comparison between the outputs shown in this report with those in TOPS-EIA focuses on the travel time impacts, vehicle operating costs, and travel time reliability.

5.2.2 Tool Inputs

As mentioned previously, travel time savings, vehicle operating costs, and travel time reliability are the major categories being investigated in this case study, while safety is evaluated as a secondary impact. Since TOPS-EIA was built upon TOPS-BC, all input values can be directly transferred between the two spreadsheets. A screenshot of how the inputs look in TOP-BC can be found in Figures B1 of the Appendices. Table 5.1 shows a list of the inputs taken from the Florida DOT report that were entered into TOPS-EIA.

The link volume shown in Table 5.1 was obtained from intersection counts conducted by the Palm Beach County Traffic Department and correspond to the average peak volume of the east approach in seven intersections during the afternoon hours (i.e., PM peak hour) Cambridge Systematics (2014). The length of the east/west corridors is approximately 8 miles and the speed limits in the project area vary between 35 and 60 mph. The free flow speed (FFS) was calculated using information from Bluetooth detectors during off-peak hours, resulting in 40 to 55 mph. The annual number of analysis periods considers not only the PM hour periods, but also a portion of the AM peak hour periods, making a total of 250 + 211 = 461 periods of analysis.

Figure 5.2 shows how the values from Table 5.1 look in TOPS-EIA. Each of these sections is explained in Chapter 4 of this report. All inputs in Table 5.1

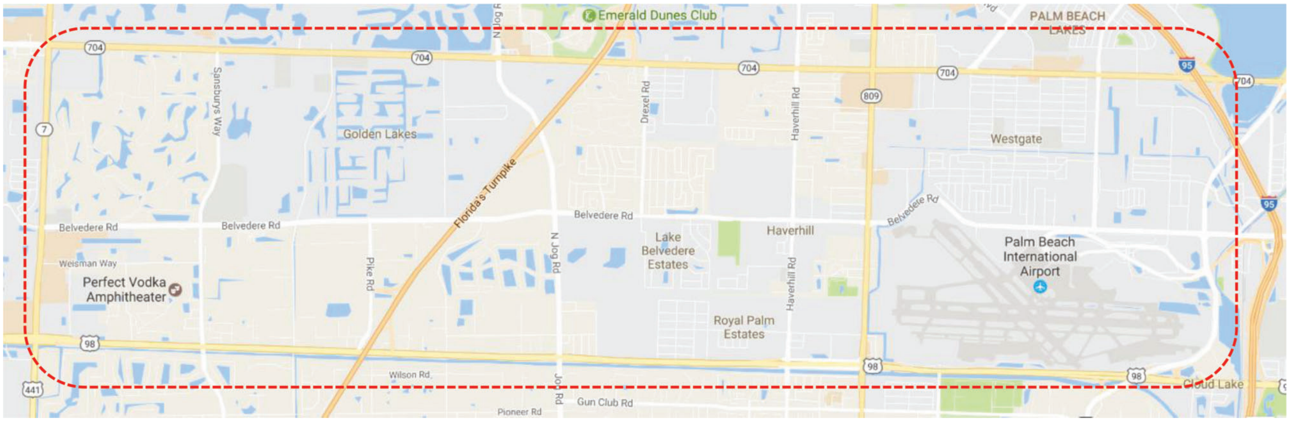


Figure 5.1 Okeechobee Blvd., Belvedere Rd., and Southern Blvd. between SR 7 and I-95. (Source: Google maps.)

TABLE 5.1
Inputs for the Okeechobee Blvd. Case Study

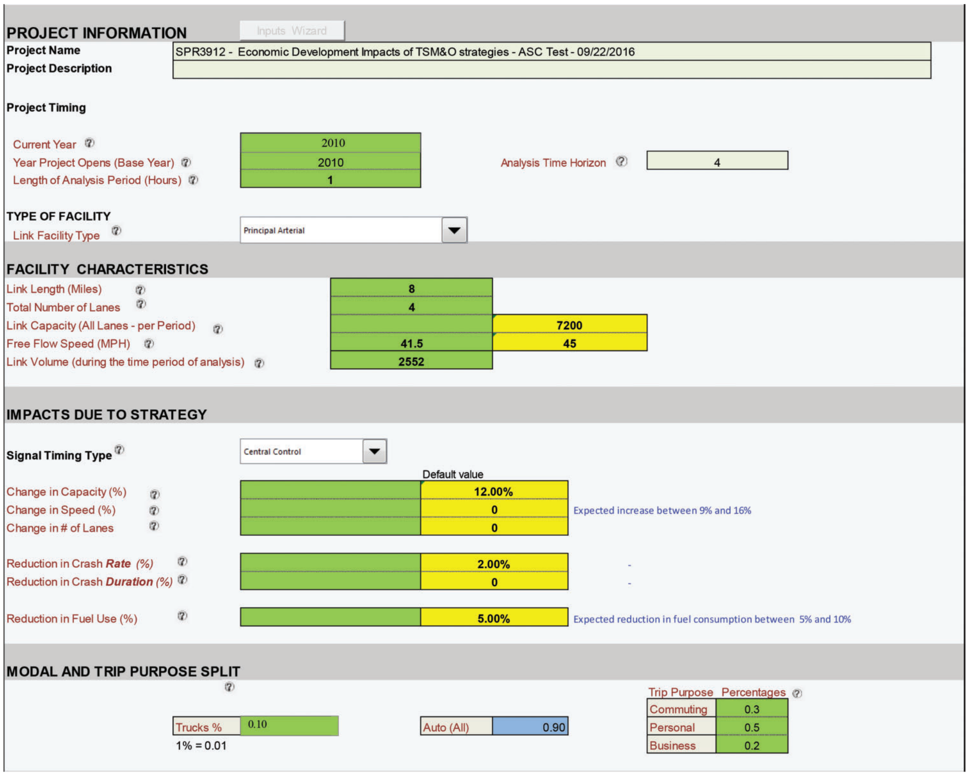
Parameters	**Value**	**Units**
Length of Analysis Period	1	hours
Facility Characteristics		
Link Facility Type	Principal Arterial	
Length	8	miles
Number of Lanes	4	lanes
Link Capacity (per period)	7200	Veh/period
Free Flow Speed	41.5	Mph
Link Volume	2552	Veh/period
Congested Speed	26	mph
Impacts Due to Strategy		
Signal Timing Type	Central Control	
Change in Capacity	12	Percent
Reduction in Crash Rate	2	Percent
Reduction in Fuel Consumption	5	Percent
Number of Analysis Periods per Year	461	Periods/year

(except the number of periods) will be entered in the first three sections of TOPS-EIA (i.e., project information, facility characteristics, and impacts due strategy). Other inputs, such as vehicle occupancy ratio, modal split, and benefit valuations, were kept with the default values provided in TOPS-BC. The modal split as well as trip purposes can be seen in section 4 of TOPS-EIA (Figure 5.2). Similarly, default values for the benefit valuations can be seen in Figure 5.3.

A step-by-step guide of how to input these values as well as sources of information can be found in the user guides of TOPS-BC (FHWA, 2013) and TOPS-EIA.

5.2.3 Application of TOPS-EIA

After the same input values were entered in both TOPS-EIA and TOPS-BC tools, the results were compared, as can be seen in Table 5.2. It should also be


PROJECT INFORMATION

Project Name	SPR3912 - Economic Development Impacts of TSM&O strategies - ASC Test - 09/22/2016
Project Description	

Project Timing

Current Year	2010
Year Project Opens (Base Year)	2010
Length of Analysis Period (Hours)	1

Analysis Time Horizon: 4

TYPE OF FACILITY
Link Facility Type: Principal Arterial

FACILITY CHARACTERISTICS

Link Length (Miles)	8	
Total Number of Lanes	4	
Link Capacity (All Lanes - per Period)		7200
Free Flow Speed (MPH)	41.5	45
Link Volume (during the time period of analysis)	2552	

IMPACTS DUE TO STRATEGY

Signal Timing Type: Central Control

		Default value	
Change in Capacity (%)		12.00%	
Change in Speed (%)		0	Expected increase between 9% and 16%
Change in # of Lanes		0	
Reduction in Crash ***Rate*** (%)		2.00%	-
Reduction in Crash ***Duration*** (%)		0	-
Reduction in Fuel Use (%)		5.00%	Expected reduction in fuel consumption between 5% and 10%

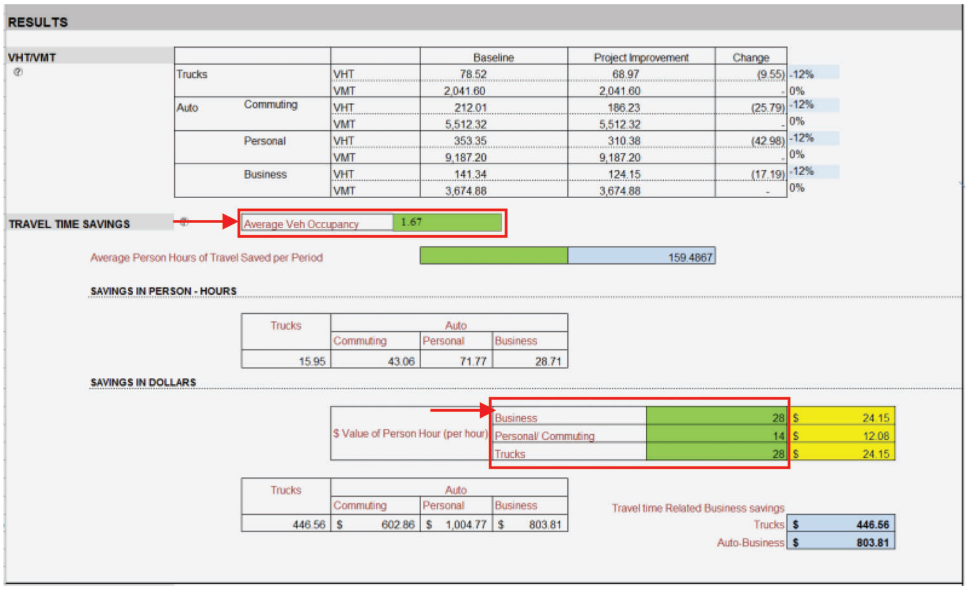
MODAL AND TRIP PURPOSE SPLIT

Trucks %	0.10
Auto (All)	0.90

1% = 0.01

Trip Purpose	Percentages
Commuting	0.3
Personal	0.5
Business	0.2

Figure 5.2 Input values in TOPS-EIA for the Okeechobee Blvd. case study.


RESULTS

VHT/VMT

			Baseline	Project Improvement	Change	
Trucks		VHT	78.52	68.97	(9.55)	-12%
		VMT	2,041.60	2,041.60	-	0%
Auto	Commuting	VHT	212.01	186.23	(25.79)	-12%
		VMT	5,512.32	5,512.32	-	0%
	Personal	VHT	353.35	310.38	(42.98)	-12%
		VMT	9,187.20	9,187.20	-	0%
	Business	VHT	141.34	124.15	(17.19)	-12%
		VMT	3,674.88	3,674.88	-	0%

TRAVEL TIME SAVINGS

Average Veh Occupancy: 1.67

Average Person Hours of Travel Saved per Period: 159.4867

SAVINGS IN PERSON - HOURS

Trucks	Auto		
	Commuting	Personal	Business
15.95	43.06	71.77	28.71

SAVINGS IN DOLLARS

$ Value of Person Hour (per hour)			
	Business	28	$ 24.15
	Personal/ Commuting	14	$ 12.08
	Trucks	28	$ 24.15

Trucks	Auto		
	Commuting	Personal	Business
446.56	$ 602.86	$ 1,004.77	$ 803.81

Travel time Related Business savings

Trucks	$ 446.56
Auto-Business	$ 803.81

Figure 5.3 TOPS-EIA: travel time savings.

TABLE 5.2
Outputs in TOPS-BC and TOPS-EIA for the Okeechobee Blvd. Case Study

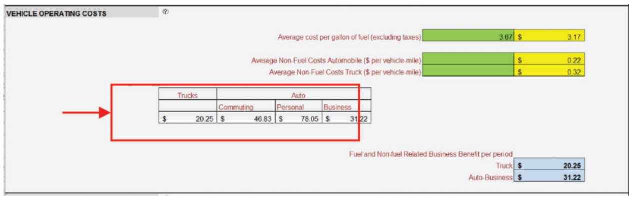
Parameter	TOPS-BC Results	TOPS-EIA Results
Average Person Hours of Travel Saved per Period	159.4867	159.4867
Travel Time Savings per Period	$2903.66	Trucks $446.6 Commuting $602.9 Personal $1004.8 Business $803.8
Fuel and Non-fuel Benefit per Period	$176.35	Trucks $20.25 Commuting $46.83 Personal $78.05 Business $31.22
Non-Recurring Delay Benefit per Period	$-0,0061	Trucks $0.02 Commuting $0.02 Personal $0.04 Business $0.03

noted that TOPS-EIA provides disaggregated outputs by mode and trip purpose; therefore, these results should be aggregated in order to make comparisons with TOPS-BC. Moreover, TOPS-EIA reports only the "business saving" benefits as final calculations (Chapter 3 and 4). Consequently, the values shown in Table 5.2 are from intermediate calculations in TOPS-EIA. Additionally, Figure B.2 in Appendix B shows the main outputs of TOPS-BC.

The dollar values for each unit of travel time were overridden using the "green cells" in TOPS-EIA to match those in the Florida DOT report. TOPS-BC reports the outputs for all purposes, including trucks, plus auto business, plus commuting and personal trips. Therefore, for the "Travel Time Savings per period", the sum of the trucks and auto vehicles yields a total of $2858 (446.56+ 602.86+1004.77+803.81) and the value from the Florida DOT report is $2902.7, which means there is a mismatch of approximately $44 (~1.5%). This difference is because TOPS-EIA has a slightly different way to handle the modal split and trip purpose split percentages, as can be seen in Chapter 4. For the Travel Time Reliability, TOPS-EIA shows the value of , which is the same result as Florida DOT report.

Similarly, the results for vehicle operating costs are the same in both TOPS-EIA and the Florida DOT report. Figure 5.3 shows the outputs for the travel time savings in TOPS-EIA. The two rectangles show the inputs for the average vehicle occupancy rate and the overridden travel time values for each of the modes and trip purposes, respectively.

Figure 5.4 shows the outputs for the vehicle operating costs savings in TOPS-EIA. The rectangle shows the values that were aggregated to compare with the outputs of TOPS-BC reported in the Florida DOT report. This figure also shows that the average cost per gallon of fuel was overridden with the corresponding value from the Florida DOT report.



VEHICLE OPERATING COSTS

Average cost per gallon of fuel (excluding taxes) 3.67 $ 3.17

Average Non-Fuel Costs Automobile ($ per vehicle-mile) $ 0.22

Average Non-Fuel Costs Truck ($ per vehicle-mile) $ 0.32

Trucks	Auto		
	Commuting	Personal	Business
$ 20.25	$ 46.83	$ 78.05	$ 31.22

Fuel and Non-fuel Related Business Benefit per period

Truck $ 20.25

Auto-Business $ 31.22

Figure 5.4 TOPS-EIA: safety and vehicle operating costs.

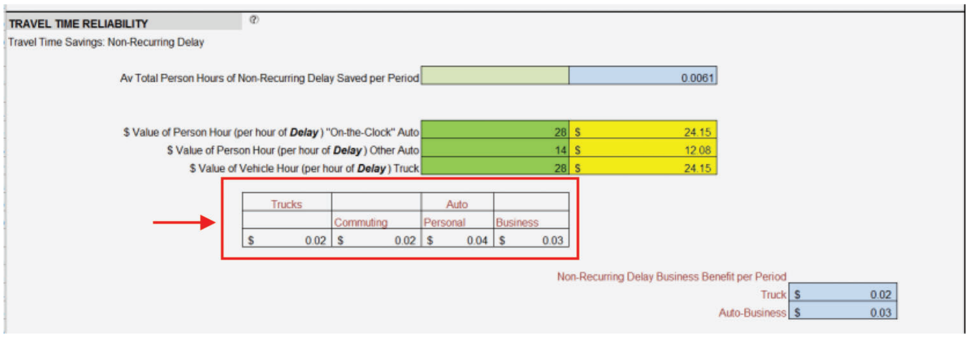
Figure 5.5 shows the outputs for the travel time reliability savings in TOPS-EIA. The rectangle shows the values that were aggregated (Table 5.2) in order to be compared with the outputs of TOPS-BC. These values were very low because they are highly dependent on the reduction in crash rate, assumed to be 2%, and the reduction in crash duration, which was assumed to be zero in this case study.

Finally, the economic development impacts of this deployment were calculated using TOPS-EIA economic multipliers. The results are shown in Figure 5.6. It could be seen that this project is expected to generate 7.5 job-years (see Chapter 4), a gross regional product of $601,000 in the 5-year time horizon of the deployment, and $634,000 on the real personal income. It should be noted that these impacts are statewide impacts and the values were calibrated for the State of Indiana.

5.3 Case Study 2: SR 37 Noblesville, Indiana

5.3.1 Project Description

This case study corresponds to a roadway segment 5.2 miles long located on State Road (SR) 37 northeast of Indianapolis, between East 126th Street and SR 38, as shown in Figure 5.7. A new signal was installed at the intersection with 135th street in 2012. During 2013, the interchange at SR 37 and I-69 was expanded to two lanes in each direction. These modifications resulted in an AADT of 38,111 vehicles per day in the corridor. One of the primary objectives of the signal optimization



TRAVEL TIME RELIABILITY

Travel Time Savings: Non-Recurring Delay

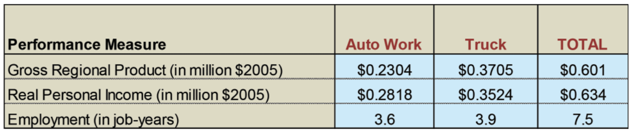
Av Total Person Hours of Non-Recurring Delay Saved per Period		0.0061
$ Value of Person Hour (per hour of ***Delay***) "On-the-Clock" Auto	28	$ 24.15
$ Value of Person Hour (per hour of ***Delay***) Other Auto	14	$ 12.08
$ Value of Vehicle Hour (per hour of ***Delay***) Truck	28	$ 24.15

Trucks		Auto	
	Commuting	Personal	Business
$ 0.02	$ 0.02	$ 0.04	$ 0.03

Non-Recurring Delay Business Benefit per Period

Truck	$ 0.02
Auto-Business	$ 0.03

Figure 5.5 TOPS-EIA: travel time reliability.



Performance Measure	Auto Work	Truck	TOTAL
Gross Regional Product (in million $2005)	$0.2304	$0.3705	$0.601
Real Personal Income (in million $2005)	$0.2818	$0.3524	$0.634
Employment (in job-years)	3.6	3.9	7.5

Figure 5.6 Statewide economic development impacts of the Okeechobee Blvd. case study.

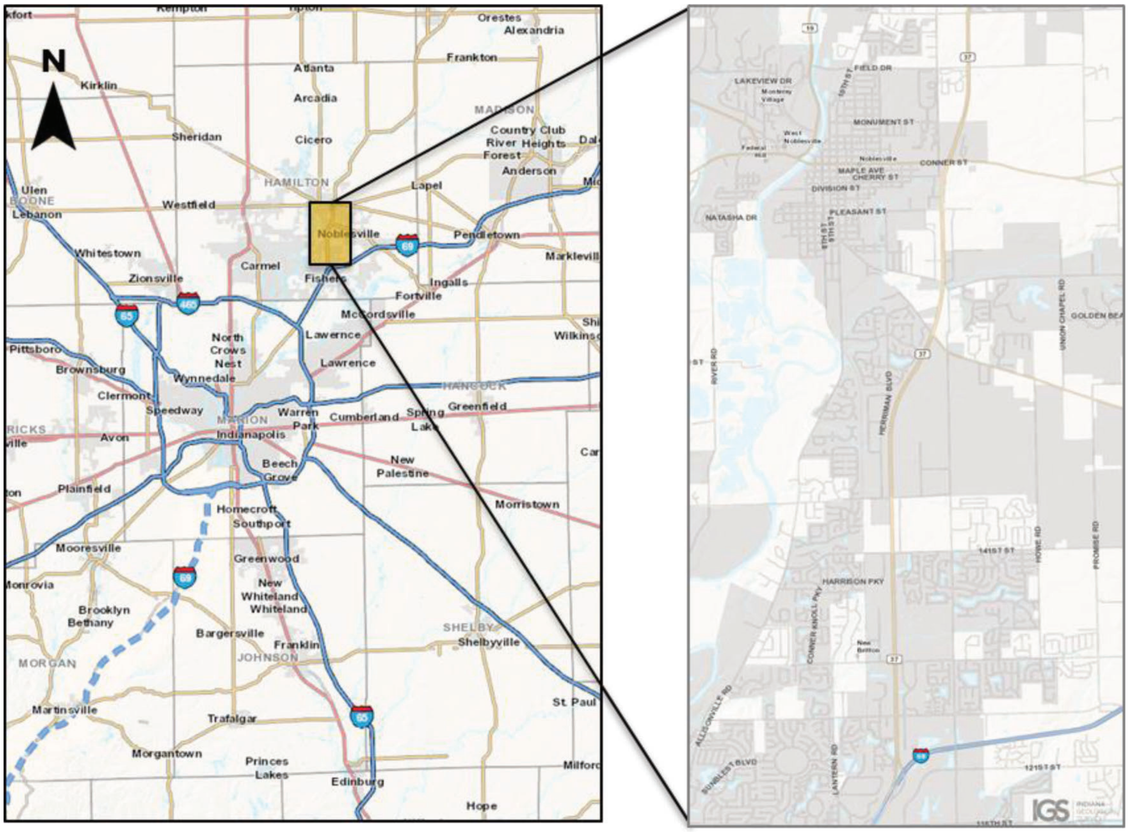


Figure 5.7 Project location of SR 37, Noblesville, Indiana. (Source: IndianaMap.org, 2016.)

project was to maximize the arrivals on green. Weekday traffic data was collected during three weeks in June before the optimization and one week in July after the optimization, 6 a.m. to 9 p.m. in 2010, as reported in Lavrenz et al. (2016). The traffic signals studied in this analysis are operated under traffic actuated control. Data was collected from eight traffic signals.

5.3.2 Tool Inputs

Table 5.3 summarizes the data retrieved from Lavrenz et al. (2016) and entered in TOPS-EIA. The inputs were retrieved for a specific time of day (i.e., analysis period) before and after the first intervention in 2010. The data considered five different periods of analysis between 6 a.m. and 7 p.m. The size of each period varies from 2-hour to 4-hour period. The analysis periods considered for this analysis was between 9 a.m. and 11 a.m. (i.e., 2-hour period of analysis). The inputs for this period are shown in Table 5.3.

Similarly, the default values for the valuation of benefits in TOPS-EIA were replaced by inputs from Lavrenz et al. (2016). These inputs are shown in Tables 5.4 and 5.5. This analysis could also be performed using data from other data sources, such as the TIGER Benefit Cost Analysis Resource Guide (USDOT, 2012).

5.3.3 Application of TOPS-EIA

State Road 37 is a four-lane principal arterial where an arterial signal coordination system was implemented.

TABLE 5.3
Inputs of the SR 37 Case Study

Parameter	Value	Units
Current Year	2015	
Year Project Opens	2010	
Length of Analysis Period	2	
Link Facility Type	Principal Arterial	
Facility Characteristics		
Link Length (Miles)	5.2	Miles
Total Number of Lanes	2	Lanes
Link Capacity	7200	Veh/period
Free Flow Speed	55	mph
Link Volume	4418	Veh/period
Impacts Due to Strategy		
Signal Timing Type	Traffic actuated	
Change in Speed	14	Percent
Modal and Trip Purpose Split		
Trucks %	2	Percent
Auto (All)	98	Percent
Auto (Business)	4.60	Percent

TABLE 5.4
Unit Cost of Travel Time Used in SR 37 Case Study (in 2015 $)

Types of Travel Time	Value of Recurring Travel Time
On-the-clock travel time	$31.04 per person hour
Other auto travel time	$15.52 per person hour
Truck travel time	$31.04 per person hour

Source: TOPS-EIA. (Based on MCIBAS 2015.)

TABLE 5.5
Unit Cost of Crashes Used in SR 37 Case Study (in 2015 $)

Crash Types	Unit Cost
Fatality	$9,800,000
Injury	$278,000
Property Damage Only (PDO)	$17,300

Source: TOPS-EIA. (Based on MCIBAS 2015.)

The expected benefits for this strategy can be seen in Table 4.1 and Table 4.2 in Chapter 4. The primary benefits associated with this strategy in TOPS-EIA are travel time savings, safety savings, and vehicle operating costs savings, while travel time reliability benefits are considered to be secondary benefits. Nonetheless, given the available data, only the travel time savings were compared with between the paper results and TOPS-EIA.

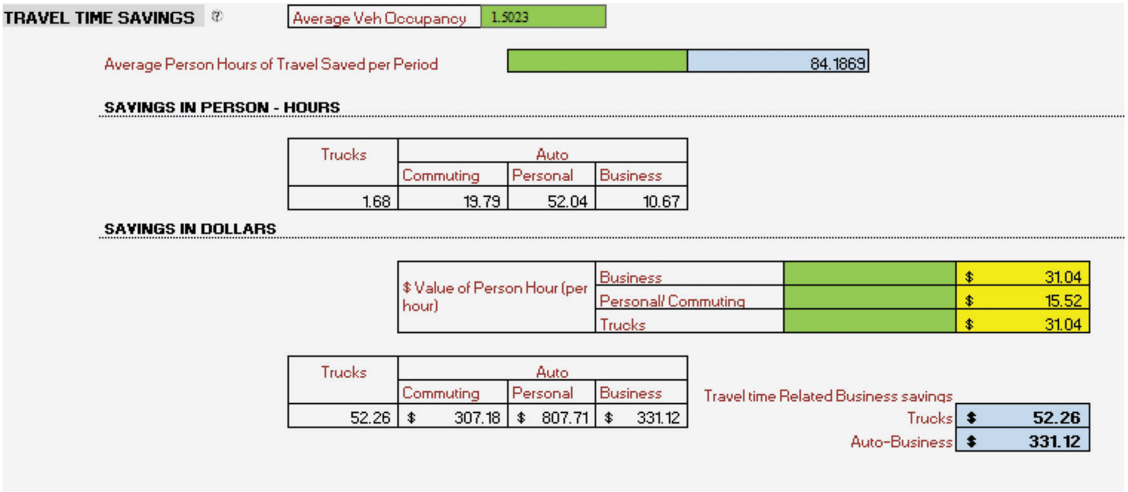
The ASC tool in TOPS-EIA can calculate the benefits for recurring travel time benefits (travel time benefits) from other auto trips, nonrecurring travel time benefits (travel time reliability benefits) from other auto trips, nonrecurring benefits from auto business trips, recurring travel time benefits from auto business trips, safety benefits from auto business trips, vehicle operating cost savings, recurring travel time benefits of trucks, and nonrecurring travel time benefits of trucks. These values were calculated using the data from Tables 5.3, 5.4, and 5.5

The free flow speed was determined using the current posted speed of 45 mph. Link volume is the average traffic volume on this segment of SR 37 over the chosen analysis period. The change in speed after applying the time of day plan that maximizes vehicle arrivals on green for the chosen analysis period was estimated to be 6.8% based on data from Lavrenz et al. (2016). The default value for link capacity provided in the tool was used.

A 3% discount rate was assumed per INDOT's suggestion. It was also assumed that business trips accounted for 4.6% of all trips on that corridor, while trucks accounted for 2% of the total average traffic volume. The default value of vehicle occupancy rate for auto (1.67) was adopted from the 2009 National Household Travel Survey (NHTS). The default value of recurring travel time for business trips ("on-the-clock" trips), personal trips, and trucks in TOPS-BC were replaced by the corresponding values in MCIBAS, as indicated in Table 5.4. Figure 3.2 and Table 4.2 indicate that reliability improvement is not the primary benefit for arterial signal coordination projects; therefore the reliability benefits were not considered in this case study.

Travel time outputs for the SR 37 case study in a typical analysis day are presented in Figure 5.8. These savings are equivalent to approximately $383.38 per period. Therefore, the annual benefits, considering 250 working days, results in more than $95,000 per year/period of analysis. These savings are then further converted to economic development impacts using the economic multipliers, as described in Chapter 4.

The results reported in Lavrenz et al. (2016) show an annual benefit of $144,873 for the selected analysis period (9 a.m. to 11 a.m.). The difference between these two values is because of the default values for the unit cost of the travel time savings in TOPS-EIA are different.



TRAVEL TIME SAVINGS

Average Veh Occupancy 1.5023

Average Person Hours of Travel Saved per Period 84.1869

SAVINGS IN PERSON - HOURS

Trucks	Auto		
	Commuting	Personal	Business
1.68	19.79	52.04	10.67

SAVINGS IN DOLLARS

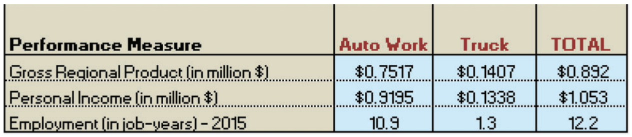
$ Value of Person Hour (per hour)			
	Business	$	31.04
	Personal/ Commuting	$	15.52
	Trucks	$	31.04

Trucks	Auto		
	Commuting	Personal	Business
52.26	$ 307.18	$ 807.71	$ 331.12

Travel time Related Business savings

Trucks	$	52.26
Auto-Business	$	331.12

Figure 5.8 TOPS-EIA outputs for SR 37, Noblesville, Indiana.



Performance Measure	Auto Work	Truck	TOTAL
Gross Regional Product (in million $)	$0.7517	$0.1407	$0.892
Personal Income (in million $)	$0.9195	$0.1338	$1.053
Employment (in job-years) - 2015	10.9	1.3	12.2

Figure 5.9 Economic development impacts of the SR 37 case study (2015 $).

5.3.4 Economic Development Impacts in TOPS-EIA

Based on the business savings calculated in the previous section, the economic development impacts for this ASC deployment were calculated using TOPS-EIA and the results are shown in Figure 5.9. For additional explanation of each of the indicators, the reader can refer to Chapters 3 and 4 of this report. From Figure 5.9 it can be seen that the deployment of the ASC system in SR37 is expected to bring 12 job-years, a gross regional product of $892,000, and $1,053,000 in real personal income, all of them over the 5-year time horizon of the deployment.

5.4 Summary

This chapter presented two examples of the application of TOPS-EIA in order to demonstrate the main inputs and outputs of the tool as well as to validate the results of the ASC tool by comparing them with case studies conducted with a similar tools or methodologies. Both case studies showed that the impacts of ASC strategies could be significant and, therefore, important to consider as part of the projects' feasibility evaluation. Similarly, the comparison of the tool outputs with the results of the case studies documented in Cambridge Systematics (2014) and Lavrenz et al. (2016) revealed similar results. The following section describes the main conclusion of this study as well as some limitations and future improvements of TOPS-EIA.

6. CONCLUSIONS

To date, non-capacity corridor improvements have received great attention from state transportation agencies because of their effectiveness in relieving congestion, improving safety, and enhancing travel time reliability at low capital, operations, and maintenance costs. Indiana, in particular, has put much effort and invested many resources over years on implementing non-capacity corridor improvements and evaluating their economic value (e.g., the Hoosier Helper Freeway Service Patrol program).

The objective of this project was to develop a tool that could be used to calculate the economic development impacts of non-traditional corridor improvements based on standard user benefits. The end product of this project is a quantifiable and user-friendly tool that can be used at the project sketch planning stage to assess the economic development impacts of different non-capacity corridor improvements by a series of well-known indicators of economic development impacts.

The following steps were completed and presented in this report:

1. A conceptual evaluation framework is proposed and examined in Chapter 2.
2. Four different options for a practical research framework are explored and discussed in Chapter 3. Additionally, a research framework that calculates the business savings and economic development impacts was developed and explained.
3. A tool was developed by extending and improving the capabilities of TOPS-BC. This tool was described in Chapter 4.
4. Two case studies were used to test the tool and described in Chapter 5.

The major contribution of this study is that it includes the demonstration of a general conceptual framework and a feasible practical research framework that can be applied for economic development impacts analysis of non-capacity corridor improvements at the state level, as well as a tool that was tested using case studies. Due to the complexity of the problem and limitations of available data, this study should be regarded as an intermediate step toward a comprehensive evaluation of the economic development effects of non-capacity corridor improvements. The tool development as well as its application is summarized in the following section.

6.1 Summary of TOPS-EIA and Case Study Results

The "Tool for Operations—Economic Impacts Assessment" (TOPS-EIA) tool was built to require the minimum amount of information in order to calculate the economic development impacts of corridor improvements. The tool builds upon a tool called, "Tool for Operations—Benefit Cost" (TOPS-BC), developed to perform benefit cost analysis of TSM&O strategies, and extends its capabilities and improves its user interface.

TOPS-EIA takes the expected impacts of each strategy on the corridor performance and translates them into, first, business cost savings and, second, economic development impacts. To do so, the tool calculates the economic savings in travel time, travel time reliability, vehicle operating costs, and safety by mode and trip purpose during the entire life of the project. Subsequently, the benefits corresponding to trucks and auto-businesses are summarized in a measure of annual business cost savings. Finally, these business cost savings are translated into economic development impacts through a set of statewide economic multipliers.

The main inputs of the tool include the length of the period of analysis, length of the segment, number of lanes, and volume of vehicles for the segment under analysis. Optional inputs include the free-flow speed, link capacity, and strategy impacts on the facility performance. The outputs of the tool cover three types of economic impacts: gross regional product (GRP) in millions of dollars, personal income in millions of dollars, and employment in job-years. These multipliers were developed for the State of Indiana than 2015; therefore, if the year of analysis is different than 2015, the tool will update the economic multipliers to the year of analysis using a set of economic deflators provided by INDOT.

An important component of TOPS-EIA is the table of expected impacts of each strategy. These tables describe the average expected impact of each strategy on the corridor performance metrics (e.g., speed). Similarly, the tables provide a range of impact values when data is available. These values were collected from the literature, including TOPS-BC, ITS database, and other case studies.

TOPS-EIA is subdivided into a set of four strategies, including traffic incident management, arterial signal coordination, work zone management, and access management. The tool was built in Microsoft Excel. Each of the strategies is presented in a separate tab where the main inputs are entered and the tool outputs are shown. Similarly, the parameters used to calculate the user benefits as well as economic impacts of each strategy are stored in a separate tab called "Parameters," where they can also be updated.

The tool was applied to two case studies using the arterial signal coordination strategy tab. The first case study is located in Palm Beach, Florida, and the inputs were taken from a report where the Florida DOT analyzed the same corridor using TOPS-BC. The second case study was located in Noblesville, Indiana, where a traffic actuated signal coordination system was implemented in a 5.2-mile corridor. The inputs for this case study were based on data from Lavrenz et al. (2016).

Both case studies showed that the expected statewide-economic development impacts could be significant. Chapter 5 shows that the expected impacts for the Palm Beach case study would be $601,000 (2005 dollars) in gross regional product (GRP) during the 4 years of the project lifetime (i.e., time horizon). Similarly, this project is expected to bring $634,000 in personal income, and 7.5 job-years during the time horizon of the project.

The Noblesville case study is expected to bring $390,000 dollars in GRP (2015 dollars), $444,000 in personal income and 5 job-year during the 5-years lifetime of the project. These impacts were calculated using statewide economic multipliers and, therefore, caution should be exercised when interpreting these results as local impacts.

Nevertheless, the economic impacts were calculated at the sketch-level of analysis; their magnitudes were significant and, thus, important to consider when evaluating the benefits of these types of projects.

In addition to TOPS-EIA, Chapter 5 also describes a second tool, which aims to estimate the expected impacts of road diet strategies. The case study search tool uses inputs such as type of strategy, land use, urban/suburban location, and traffic volume to provide the analyst with a list of case studies with similar characteristics and their reported impacts. The outputs show the location of the projects, along with a brief description of the application, impacts on average crash rate, average corridor speed, traffic diversion, impacts on local businesses, and impacts on other modes of transportation. The data contained in the database of the case search tool was retrieved from the published case study compilations, papers, and reports. Therefore, not all the impact categories might be available for every case study. A total of 60 case studies are presented in this database and the tool was designed to facilitate the aggregation of additional case studies.

6.2 Applicability and Limitations of TOPS-EIA

TOPS-EIA can be used for the analysis of the economic impacts of four types of corridor improvements:

1. Traffic incident management strategies,
2. Arterial signal coordination,
3. Work zone management, and
4. Access management.

The tool was developed for the initial stages of the project development process, where various project alternatives or configurations can be analyzed with a low level of detail in the inputs and outputs. Therefore, TOPS-EIA can be used for the screening of projects' impacts, project prioritization, or multi-criteria analysis (MCA).

Similarly, intermediate outputs of the tool such as user benefits (e.g., travel time savings) can be used in benefit-cost analysis (BCA). However, the latter will require the calculation of project costs, which is not covered in TOPS-EIA. For MCA, different indicators such as GRP, personal income, employment and any of the intermediate outputs generated by the tool can be incorporated directly as criteria in the decision-making process. The main advantage of MCA is its robustness with respect to double-counting or overlaps of benefits. However, depending on the inputs used, the definition of "users" might need to be redefined, because the economic development benefits measured by the tool are statewide impacts.

It should also be noted that, because the tool uses the same parameters used in MCIBAS-SEAT, the outcomes of both tools can be compared if the differences in the time horizons are taken into account. Therefore, the planning process can consider both capacity expansion and non-capacity expansion projects in the same analysis.

The following section presents some additional points that should be considered when applying TOPS-EIA. These points could be seen as limitations of TOPS-EIA and/or opportunities for future improvements in the tool.

6.2.1 Limitations of TOPS-EIA

- One limitation in the tool is that the benefits of each strategy are analyzed independently. This means that TOPS-EIA cannot account for the possible synergies of the implementation of multiple strategies on the same corridor. Therefore, if a project has more than one type of strategy, the benefits of each individual project cannot be added directly. Similarly, the interaction of the corridor improvement with existing infrastructure features (e.g., existing dynamic message signs or red-light cameras) cannot be captured by the tool. This limitation, however, could be overcome by appropriately overriding the expected impacts of each strategy to adapt them to local conditions of the corridor.
- The implementation of non-capacity corridor improvements can promote a region's economy through increasing GDP, creating jobs, and enhancing personal income. Deploying a group of non-capacity corridor improvements to a transportation network has the potential of stimulating a state's economic development. However, the effect of these corridor improvements on economic development cannot be isolated in this analysis from the effect that other factors that could have on economic development at the same time (such as growth in businesses and business attraction).
- The default unit costs of travel time reliability and unit costs of travel time are the same. That is, the reliability ratio is fixed to be 1. However, some literature (e.g., SHRP2, 2014) suggests that the value of travel time reliability could differ significantly from the value of travel time, depending on the type of industry that the corridor serves. Therefore, users can overwrite the default unit costs of travel time reliability with more accurate values to reflect its importance to business productivity. Reliable sources include the Second Strategic Highway Research Program (SHRP2, 2014). For instance, in the EconWorks W.E.B. reliability tool, the unit cost of travel time reliability for passenger trips is suggested to be $14.90 per person-hour, and $29.87 per person-hour for commercial trips (SHRP2, 2014).
- TOPS-EIA does not take into account either induced travel or consumer surplus. As discussed in Chapter 3, an accurate estimate of induced travel is important to the estimation of travel time. If users of the tool perceive the possibility of induced travel because of the implementation of nontraditional corridor improvements, they have to identify the source of the induced trips (route changes or mode shifts), and then accurately include them by either adjusting the traffic volume or changing the auto vehicle occupancy rate.
- Although TOPS-EIA is able to account for nonrecurring congestion, as indicated in Section 3.2.1.2, a more detailed breakdown of nonrecurring congestion sorted by causes can be added. This effort has been undertaken by, for example, the Second Strategic Highway Research Program (FHWA, 2012).
- The current version of TOPS-EIA estimates accidents simply by applying a static rate for crashes (fatality crash, injury crash, and property damage only) to the overall changes in VMT for both passenger cars and trucks. This estimation approach could be enhanced by elaborating the crash rate in a more dynamic manner, calculating it based on vehicle types (auto and trucks), facility types (freeway vs. arterial vs. rural road), roadway configuration geometrics (ramp, interchanges), existing roadway safety installations, facility speeds, facility congestion levels (revealed by the volume capacity ratio), and historical crash occurrence (FHWA, 2012).
- TOPS-EIA does not count emission benefits automatically, although the unit costs of several pollutants are displayed on its "Parameter" tab (as inherited from TOPS-BC). Similarly, although TOPS-EIA provides users' unit cost of noise per VMT by auto and truck, it does not calculate the noise benefits.
- TOPS-EIA does not estimate customer satisfaction and agency efficiency associated with nontraditional corridor improvements. Instead, it defines them as measure of effectiveness (MOEs) that are "hard-to-quantify" (FHWA, 2012).
- The economic multipliers used in TOP-EIA reflect statewide impacts. Therefore, they are used independently of the region where the project is located. An important advantage of this is that the projects evaluated in TOPS-EIA can be directly compared with capacity expansion projects analyzed with tools using similar parameters (e.g., MCIBAS-SEAT).
- Regarding the table of impacts in the tool, the sparseness of secondary data sources (i.e., past reports or papers) is an important limitation to the ability of this report to draw a more persuasive conclusion about the impacts of nontraditional corridor improvements on the state's economic development. Future research can validate the proposed research framework using a larger pool of projects, collecting field data, or running simulations. Also, this report did not evaluate the benefits of nontraditional

corridor improvements related to reduction in noise levels. Future research could explore whether such benefits could affect economic development as well.

- Finally, the tool emphasizes the assessment of the economic development impacts caused by the savings of business travel costs from the implementation of non-traditional corridor improvements. Future research could explore the influence of other factors. For instance, additional economic benefits triggered by improvements of market accessibility or enhancements of intermodal connectivity.

7. ACKNOWLEDGMENTS

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APPENDICES

APPENDIX A

TABLE A.1
State DOT Experience with Input-Output Models

Tools	Case Study	Year	Agency	Purpose	Measurements
IMPLAN	The Economic Impact of Aviation in Arizona	2013	Arizona DOT	To estimate the economic impact of aviation in Arizona	Economic output or activity, employment, and earnings
RIMS II/Internal Multiplier Model	Louisiana Marine Transportation System Plan	2007	Louisiana DOT	To determine the impact of Louisiana's extensive navigable waterway system on the state's economy and to identify infrastructure improvements to optimize the system's operational efficiency for future economic growth	Business sales, number of jobs created, value added, overall growth of economic activities, increased state and federal taxes income, environmental and quality of life impacts

TABLE A.2
State DOT Experience with MCIBAS

Case Study	Year	Agency	Purpose	Measurements
Economic Impacts of Indiana's Statewide Long Range Transportation Plan		Indiana DOT	To evaluate the economic impacts of Economic Impacts of Indiana's Statewide Long Range Transportation Plan	Travel time, cost, and safety improvements, environmental and aesthetic benefits, real personal income, gross state product, output, and employment

TABLE A.3
State DOT Experience with TREDIS

Case Study	Year	Agency	Purpose	Measurements
Economic Impacts of Express Toll Lanes in the Chicago Region	2012	Chicago Metropolitan Agency	To address how congestion would affect the regional economy	Traveler costs, market access impacts, business output, number of new jobs
The Cost of Highway Limitations and Traffic Delay to Oregon's Economy	2007	Oregon Business Council, Portland Business Alliance, Associated Oregon Industries, Port of Portland, Oregon DOT, and Westside Economic Alliance	To justify the value of transportation investment	Travel cost impacts, market access impacts, direct traveler benefits, benefits to business, society benefits
Economic Benefits of KDOT Highway Preservation Funding	2008	Kansas DOT	To demonstrate the economic importance of maintaining needed funding for highway system preservation	Changes in statewide employment, business output, value added, wages, jobs, and reduced rehab spending
I-70 Dedicated Truck Lanes	2010	Indiana DOT Illinois DOT Ohio DOT Missouri DOT	To justify the value of adding four dedicated truck lanes (two in each direction) along I-70	Changes in earnings and number of jobs created
South Coast Commuter Rail Service	2009	Massachusetts DOT	To examine the feasibility of establishing commuter rail service to the state's south coast region	Region's quality of life, business attraction, and economic growth
Kansas DOT Expended Highway Section Program	2003	Kansas DOT	To be more responsible for the public when making project selection decisions	Number of jobs created, change in net present value of study area, study area gross regional product, and safety benefits

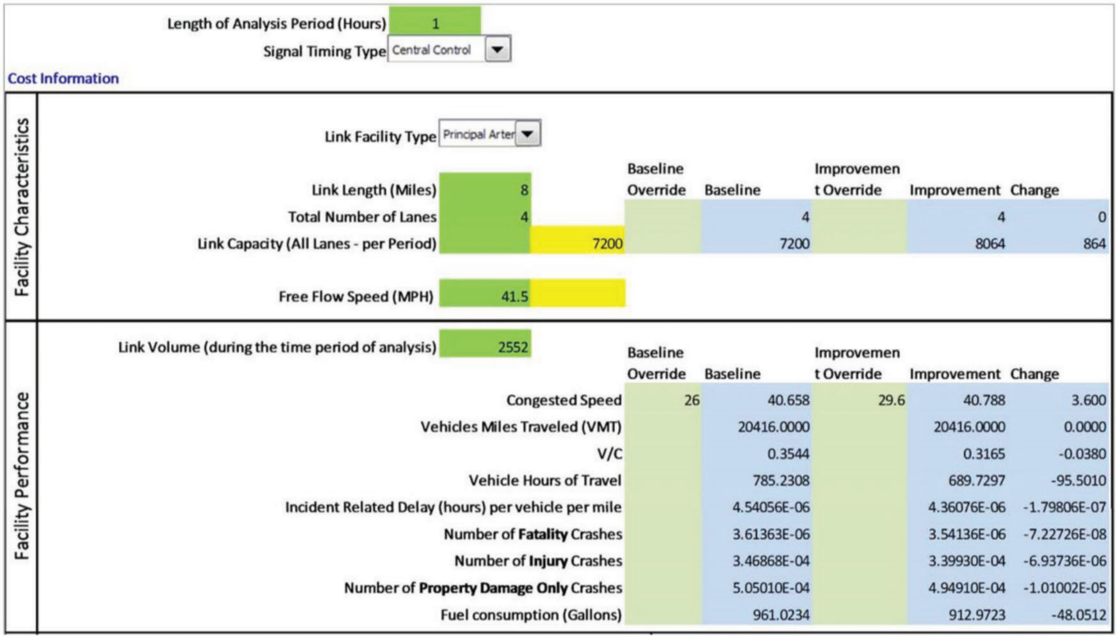
TABLE A.4
State DOT Experience with REMI

Case Study	Year	Agency	Purpose	Measurements
Congestion Pricing: Economic Impact of Tolling		Oregon DOT	To quantify the economic effects of tolling scenarios on OR 217 and Cornelius Pass Road; To analyze the social economic costs of tolling and identify the benefit levels that would be needed from toll—financed programs to achieve economic break-even; To access key economic externalities and other factors relevant to a tolling program for OR 217 and Cornelius Pass Road	Changes in earnings, output, employment, and overall economic costs or benefits
Economic Impact of the Appalachian Development Highway System	1998	Appalachian Regional Commission	To measure the restricted 12 corridors, in retrospect, the extent to which the completed portions of the ADHS have contributed to the economic well-being of Appalachia	Number of jobs created, changed in wages, and changes in value added
The Economic Impact of the Proposed Pennsylvania Turnpike and Interstate 95 Interchange	2000	The Pennsylvania Turnpike Commission	To justify the value of building a direct interchange between the Pennsylvania Turnpike and Interstate 95 in Lower Bucks County	Number of jobs created, increased business sales, and total employment growth
Economic Impacts of Florida's Transportation Investment (A Macroeconomic Analysis)	2009	Florida DOT	To analyze the long term economic impacts of the Florida DOT work program	Increased personal income, number of jobs created, gross regional product, and productivity
Expanding US Highway 54 in New Mexico: Assessing Economic Effects	2004	New Mexico DOT	To forecast the full economic impacts of expending US highway 54 in New Mexico in terms of construction spending and improved travel efficiency	Gross regional product, number of jobs created, and relative cost of production
Iliana Expressway Economic Opportunities Analysis	2010	Illinois DOT	To quantify the potential benefits from the Iliana expressway and assess the extent to which they may lead to businesses attraction opportunities for the region	Job creations, personal income, employment, and gross regional product
Economic Impact Analysis of Michigan Transportation Investment Packages	2007	Michigan DOT	To examine the potential economic impacts to Michigan's economy when MDOT invests in the improvement and maintenance of the state's transportation system	Total employment, gross state product, personal income, and personal travel time savings
Impacts of Transportation Infrastructure on the Economy of North Dakota	2007	North Dakota DOT	To justify the value of transportation investment	Job creations, wages, and generated revenue
Infrastructure Investment Would Benefit South Georgia	2000	Georgia General Assembly, Carl Vinson Institute of Government, The University of Georgia	To forecast the economic impacts of a major infrastructure investment in south Georgia	Number of jobs created, annually increased gross regional product, and annually increased state revenue
Economic Impact of the Appalachian Development Highway System	1998	Appalachian Regional Commission	To measure the restricted 12 corridors, in retrospect, the extent to which the completed portions of the ADHS have contributed to the economic well-being of Appalachia	number of jobs created, changed in wages, and changes in value added
The Economic Impact of the Proposed Pennsylvania Turnpike and Interstate 95 Interchange	2000	The Pennsylvania Turnpike Commission	To justify the value of building a direct interchange between the Pennsylvania Turnpike and Interstate 95 in Lower Bucks County	number of jobs created, increased business sales, and total employment growth
Economic Impacts of Florida's Transportation Investment (A Macroeconomic Analysis)	2009	Florida DOT	To analyze the long term economic impacts of the Florida DOT work program	increased personal income, number of jobs created, gross regional product, and productivity

TABLE A.4
(Continued)

Case Study	Year	Agency	Purpose	Measurements
Expanding US Highway 54 in New Mexico: Assessing Economic Effects	2004	New Mexico DOT	To forecast the full economic impacts of expending US highway 54 in New Mexico in terms of construction spending and improved travel efficiency	gross regional product, number of jobs created, and relative cost of production
Iliana Expressway Economic Opportunities Analysis	2010	Illinois DOT	To quantify the potential benefits from the Iliana expressway and assess the extent to which they may lead to businesses attraction opportunities for the region	Job creations, personal income, employment, and gross regional product
Economic Impact Analysis of Michigan Transportation Investment Packages	2007	Michigan DOT	To examine the potential economic impacts to Michigan's economy when MDOT invests in the improvement and maintenance of the state's transportation system	Total employment, gross state product, personal income, and personal travel time savings
Impacts of Transportation Infrastructure on the Economy of North Dakota	2007	North Dakota DOT	To justify the value of transportation investment	Job creations, wages, and generated revenue
Infrastructure Investment Would Benefit South Georgia	2000	Georgia General Assembly, Carl Vinson Institute of Government, The University of Georgia	To forecast the economic impacts of a major infrastructure investment in south Georgia	Number of jobs created, annually increased gross regional product, and annually increased state revenue

APPENDIX B



Length of Analysis Period (Hours) 1

Signal Timing Type Central Control

Cost Information

Facility Characteristics

Link Facility Type Principal Arter

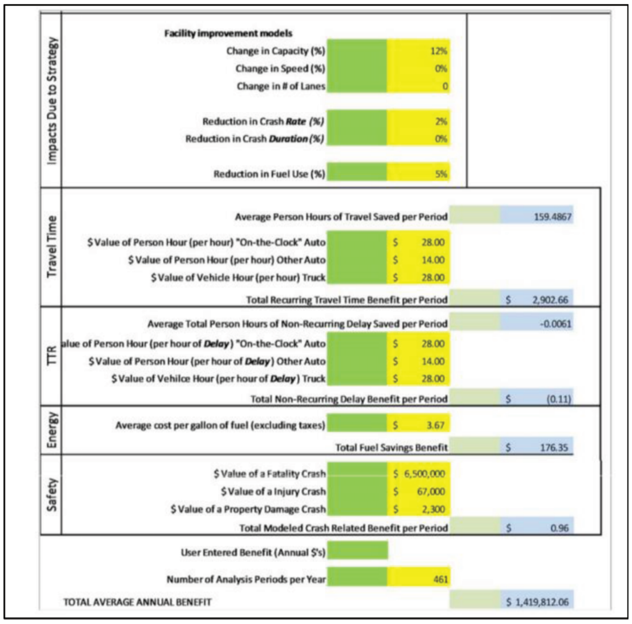
			Baseline Override	Baseline	Improvement Override	Improvement	Change
Link Length (Miles)	8						
Total Number of Lanes	4			4		4	0
Link Capacity (All Lanes - per Period)		7200		7200		8064	864
Free Flow Speed (MPH)	41.5						

Facility Performance

Link Volume (during the time period of analysis) 2552

	Baseline Override	Baseline	Improvement Override	Improvement	Change
Congested Speed	26	40.658	29.6	40.788	3.600
Vehicles Miles Traveled (VMT)		20416.0000		20416.0000	0.0000
V/C		0.3544		0.3165	-0.0380
Vehicle Hours of Travel		785.2308		689.7297	-95.5010
Incident Related Delay (hours) per vehicle per mile		4.54056E-06		4.36076E-06	-1.79806E-07
Number of **Fatality** Crashes		3.61363E-06		3.54136E-06	-7.22726E-08
Number of **Injury** Crashes		3.46868E-04		3.39930E-04	-6.93736E-06
Number of **Property Damage Only** Crashes		5.05010E-04		4.94910E-04	-1.01002E-05
Fuel consumption (Gallons)		961.0234		912.9723	-48.0512

Figure B.1 TOPS-BC traffic signal coordination system inputs. (Source: Cambridge Systematics, 2014.)



Impacts Due to Strategy

Facility improvement models

Change in Capacity (%)	12%	
Change in Speed (%)	0%	
Change in # of Lanes	0	
Reduction in Crash ***Rate*** (%)	2%	
Reduction in Crash ***Duration*** (%)	0%	
Reduction in Fuel Use (%)	5%	
Travel Time		
Average Person Hours of Travel Saved per Period		159.4867
$ Value of Person Hour (per hour) "On-the-Clock" Auto	$ 28.00	
$ Value of Person Hour (per hour) Other Auto	$ 14.00	
$ Value of Vehicle Hour (per hour) Truck	$ 28.00	
Total Recurring Travel Time Benefit per Period		$ 2,902.66
TTR		
Average Total Person Hours of Non-Recurring Delay Saved per Period		-0.0061
alue of Person Hour (per hour of ***Delay***) "On-the-Clock" Auto	$ 28.00	
$ Value of Person Hour (per hour of ***Delay***) Other Auto	$ 14.00	
$ Value of Vehilce Hour (per hour of ***Delay***) Truck	$ 28.00	
Total Non-Recurring Delay Benefit per Period		$ (0.11)
Energy		
Average cost per gallon of fuel (excluding taxes)	$ 3.67	
Total Fuel Savings Benefit		$ 176.35
Safety		
$ Value of a Fatality Crash	$ 6,500,000	
$ Value of a Injury Crash	$ 67,000	
$ Value of a Property Damage Crash	$ 2,300	
Total Modeled Crash Related Benefit per Period		$ 0.96
User Entered Benefit (Annual $'s)		
Number of Analysis Periods per Year	461	
TOTAL AVERAGE ANNUAL BENEFIT		$ 1,419,812.06

Figure B.2 TOPS-BC traffic signal coordination system benefits. (Source: Cambridge Systematics, 2014.)

APPENDIX C

TABLE C.1
Range of Impacts for Arterial Signal Coordination Strategies

ASC Type	Indicator	ASC TIM Impacts
1. Preset Timing—Corridor	Reduction in Crash Rate (%) Reduction in Fuel Use (%)	Expected reduction between 2% and 7% Expected reduction in fuel consumption rates between 2% and 8%
2. Traffic Actuated—Corridor	Change in Speed (%) Reduction in Fuel Use (%)	Expected increase between 8% and 20% Expected decrease in fuel consumption between 6% and 13%
3. Central Control—Corridor	Change in Speed (%) Reduction in Fuel Use (%)	Expected increase between 9% and 16% Expected reduction in fuel consumption between 5% and 10%

TABLE C.2
Range of Impacts for Traffic Incident Management Strategies

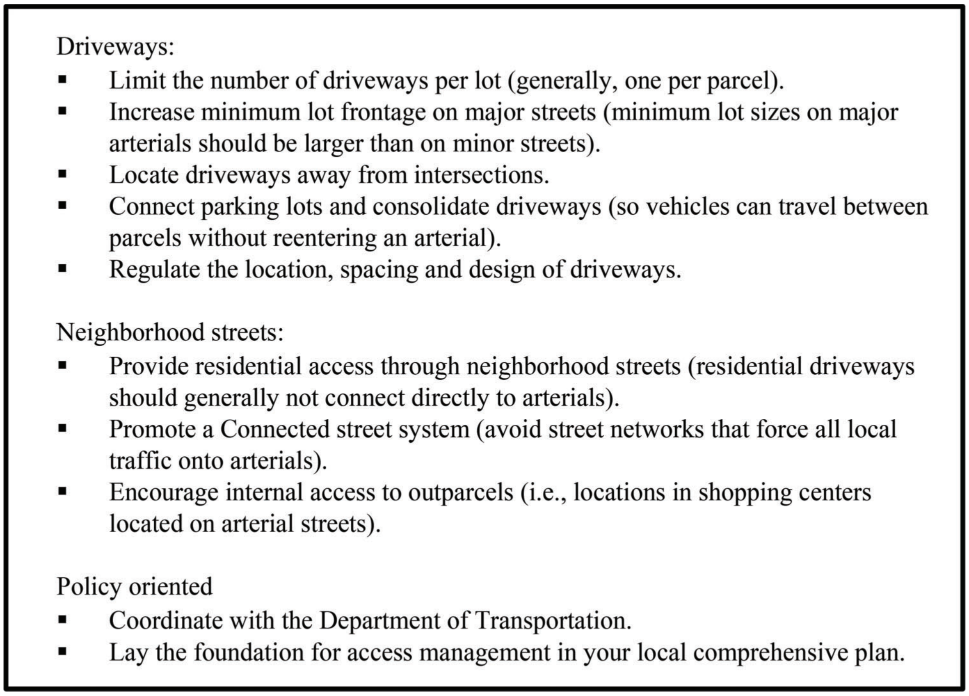
Indicator	TIM Impacts	Comments
Change in Speed (%)	Expected reduction between 8% and 20%	Based on Combination Detection & Response application
Reduction in Crash Rate (%)	Expected reduction between 15% and 50% (Combination of detection & response strategies)	Based on Combination Detection & Response applications Indiana—Hoosier Helper reduces probability of secondary crash by 18.5% during the winter and 36.3% during the other 3 seasons
Reduction in Crash Duration (%)	Expected reduction between 40% and 60% (Combination of detection & response strategies)	Based on Combination Detection & Response applications
Reduction in Fatality Crash Rate (%)	Expected reduction between 5% and 15% (Incident detection/verification strategies)	Based on "Incident Detection/Verification" applications
Reduction in Fuel Use (%)	Expected reduction up to 42% (Combination of detection & response strategies)	Based on IDAS (Combination Detection & Response)

TABLE C.3
Range of Impacts for Work Zone Management Strategies

Indicator	WZM Impact	Comment
Change in Speed (%)	Expected speed increase between 9% and 15%	Lower range value based on Mobile Barrier Trailer (MBT-1) application, Upper range value based on Dynamic lane merge system (DLM) application
Reduction in Crash Rate (%)	Expected reduction up to 40%	Based on Traffic and Incident Management System (TIMS) on I-95 in Philadelphia
Reduction in Crash Duration (%)	Expected reduction in clearance time up to 45%	Based on Albuquerque, NM "Big I" interchange
Reduction in Fatality Crash Rate (%)	Expected reduction up to 30%	Based on Lonoke County, AK I-40 study, Based on CCTV, DMS, Arrow Signs, Portable Traffic Management Systems, and Highway Advisory Units

TABLE C.4
Range of Impacts for Access Management Strategies

AM Type	Indicator	AM Impact	Comment
1. Crash Rates for Two-Lane Undivided and Three-Lane TWLTL	Reduction in Crash Rate (%)	Between 35% and 13% reduction for non-intersection	Source: NCHRP Report 282 California & Michigan Roads (Suburban area) (2008) (California and Michigan Roads)
		Between 15% and 34% reduction for signalized intersection	Source: CMF clearinghouse (www.cmfclearinghouse.org/)
		Between 11% and 20% reduction depending on the total number of access points per mile (signalized and unsignalized)	Source: NCHRP Report 420, Impacts of Access Management Techniques. Figure 24. Gluck, Levinson, Stover (1999). Transportation Research Board.
2. Provide a Raised Median	Reduction in Crash Rate (%)	Between 17% and 67% reduction in all types of crashes	Source: CMF clearinghouse (www.cmfclearinghouse.org/)
		Between 23% and 30% reduction depending on the total number of access points per mile (signalized and unsignalized)	Source: NCHRP Report 420, Impacts of Access Management Techniques. Figure 24. Gluck, Levinson, Stover (1999). Transportation Research Board.
3. Increase Signal Spacing	Change in Speed (%)	Increase in travel time of 9% to 39% when compared to a baseline of a corridor with 2 signals per mile	Source: NCHRP Report 420, Impacts of Access Management Techniques (1999)



Driveways:

- Limit the number of driveways per lot (generally, one per parcel).
- Increase minimum lot frontage on major streets (minimum lot sizes on major arterials should be larger than on minor streets).
- Locate driveways away from intersections.
- Connect parking lots and consolidate driveways (so vehicles can travel between parcels without reentering an arterial).
- Regulate the location, spacing and design of driveways.

Neighborhood streets:

- Provide residential access through neighborhood streets (residential driveways should generally not connect directly to arterials).
- Promote a Connected street system (avoid street networks that force all local traffic onto arterials).
- Encourage internal access to outparcels (i.e., locations in shopping centers located on arterial streets).

Policy oriented

- Coordinate with the Department of Transportation.
- Lay the foundation for access management in your local comprehensive plan.

Figure C.1 Alternative classification of access management strategies. (Adapted from TDM, 2014.)

APPENDIX D

TABLE D.1
Access Management—Trip Ends

Land Use Category	Vehicle Trip Ends (Average Peak Hour)	Vehicle Trip Ends (PM Peak period)	Notes	Weighted Average Daily Trip Ends (Entering and leaving)	Average Sq. Feet GFA	Notes
Gasoline service station (with conv. store)	0.05	0.05	See note 1.A	876	1,000	See note 1.B
Supermarkets	173.9	256.5	See note 4.A	2664	27,000	See note 4.B
Convenience market (open 15–16 hours)	65.6	69.1	See note 2.A	688	2,000	See note 2.B
Fast food restaurant with drive through window	0.24	0.12	See note 5.A	1532	3,000	See note 5.B
High turnover sit-down restaurant	72.3	69.3	See note 6.A	661	7,000	See note 6.B
Department stores	118.8	181.4	See note 7.A	2234	97,000	See note 7.B
Small retails	54.5	73.9	See note 3.A	722	6,750	See note 3.B

All notes are based on the ITE Trip Generation Manual (9th Edition).

(1.A) Trip ends as a function of traffic on adjacent street. Average rate of trip ends as a function of traffic on adjacent street. Average value for AM peak period (0.04 per 1000 sq feet) and PM peak period (0.05 per 1000 sq feet) of adjacent street traffic. Land use 944. Pages 1989 and 1990.

(2.A) Average rate for AM peak period (31.02 per 1000 sq feet) and PM peak period (34.57 per 1000 sq feet) of adjacent street traffic. Land use 852. Pages 1665 and 1666.

(3.A) Land use 843 (Automobile Parts Sales, pages 1607 and 1608), 848 (Tire Store, pages 1613 and 1614), 880 (Pharmacy/Drugstore without Drive-Through Window, pages 1796 and 1797), and 912 (Drive-in bank, pages 1843 and 1844)

(4.A) Average rate for AM peak period (3.4) and PM peak period (9.5) of adjacent street traffic. Land use 850. Pages 1646 and 1647.

(5.A)Trip ends as a function of traffic on adjacent street. Average rate of trip ends as a function of traffic on adjacent street. Average value for AM peak period (0.12) and PM peak period (0.04) of adjacent street traffic. Land use 934. Pages 1930 and 1931.

(6.A) Average rate for AM peak period (10.8) and PM peak period (9.9) of adjacent street traffic. Land use 932. Pages 1886 and 1887.

(7.A) Average rate for AM peak period (0.58) and PM peak period (1.87) of adjacent street traffic. Land use 1562. Pages 1781 and 1782.

(1.B) Based on average AM (78.06) and PM (97.14) peak hour of generator for land use 945. Pages 1999 and 2000. Peak hour volume represents the 10% of daily volume.

(2.B) Based on average AM (32.60*3) and PM (36.22*3) peak hour of generator for land use 852. Pages 1667 and 1668. Peak hour volume represents the 10% of daily volume.

(3.B) Land use 843 (Automobile Parts Sales, Page 1606), 848 (Tire Store, page 1617), 880 (Pharmacy/Drugstore *without* Drive-Through Window, page 1795), and 912 (Drive-in bank, pages. 1842, 1847, and 1849)

(4.B) Weighted average daily trip ends. Weekday (102*27), Saturday (177.59*27), and Sunday (166.44*27). Pages 1645, 1650, and 1652. Note: rates have small sample size.

(5.B) Weighted average daily trip ends. Weekday (462*3), Saturday (722*3), and Sunday (542.72*3). Pages. 1912, 1917, and 1919.

(6.B) Average daily trip ends weekday, Saturday and Sunday. Land use 932. Page 1885.

(7.B) Weighted average daily trip ends. Weekday (22.08*97) and Saturday (25.4*97). Pages 1780 and 1781.

TABLE D.2
Pass-By Trips

Land Use Category	Pass-By Trips (Percentage)	Notes
Gasoline service station (with conv. store)	50%	See note 8
Supermarkets	36%	See note 11
Convenience market (open 15–16 hours)	61%	See note 9
Fast food restaurant with drive through window	50%	See note 12
High turnover sit-down restaurant	43%	See note 13
Department stores	33%	See note 14
Department stores	33%	See note 14
Small retails	23%	See note 10
Other 1		
Other 2		

All notes are based on the ITE Trip Generation Handbook, Chapter 5.
(8) Average AM (58%) and PM (42%) peak periods. Land use 944. Tables 5.27 and 5.28.
(9) PM peak period. Land use 851. Table 5.11.
(10) Average PM peak period for land use 843, 848, 880, and 912. Tables 5.5, 5.8, 5.9, 5.17, and 5.20.
(11) PM peak periods. Land use 850. Table 5.10.
(12) Average AM (49%) and PM (50%) peak periods. Land use 934. Tables 5.23 and 5.24.
(13) PM peak period. Land use 932. Table 5.22.
(14) Weighted average weekday PM (34%) and Saturday midday (26%) peak periods. Land use 820. Tables 5.6 and 5.7.
Meaning of 2012 NAICS code
(15) Gasoline stations with convenience stores
(16) Supermarkets and other grocery (except convenience) stores
(17) Convenience stores
(18) Limited-service restaurants
(19) Full-service restaurants
(20) Cafeterias, grill buffets, and buffets
(21) Department stores
(22) Automotive parts and accessories stores
(23) Tire dealers
(24) Pharmacies and drug stores
(25) Credit unions
(26) Factor of 3.11 based on CPI inflation calculator from BLS from 2012 to 2015

TABLE D.3
Dollar Purchase Value per Customer

Business Category	2012 NAICS Code	Note	Number of Establishments	Value of Sales, Shipments, Receipts, Revenue, or Business Done ($1,000), 2012	Average Annual Sales per Establishment ($1000 /yr.)	Average Daily Sales per Establishment	Weighted Average Daily Trip Ends (entering and leaving)	Customers per Day (50% trip ends)	Purchase per Customer (2012 $)	Purchase per Customer (2015 $)
Gasoline service station (with conv. store)	44711	See note 15	2,217	9,620,869	4,340	12,054.41	876	438	27.52	28.38
Supermarkets	44511	See note 16	1,016	8,805,019	8,666	24,073.21	2,664	1,332	18.07	18.63
Convenience market (open 15–16 hours)	44512	See note 17	207	160,690	776	2,156.33	688	344	6.27	6.46
Fast food restaurant with drive through window	722513	See note 18	4,676	3,996,512	855	2,374.13	1,532	766	3.10	3.20
High turnover sit-down restaurant	722511	See note 19	4,419	4,036,660	917	2,546.17	661	331	7.70	7.94
	722514	See note 20	189	187,124						
Department stores	4521	See note 21	178	3,016,576	16,947	47,075.16	2,234	1,117	42.15	43.46
Small retails	44131	See note 22	897	1,067,071	2,893	8,036.13	722	361	22.27	22.97
	44132	See note 23	443	772,727.00						
	44611	See note 24	815	4,968,964.00						
	52213	See note 25	543	996,573.00						

Meaning of 2012 NAICS code
(15) Gasoline stations with convenience stores
(16) Supermarkets and other grocery (except convenience) stores
(17) Convenience stores
(18) Limited-service restaurants
(19) Full-service restaurants
(20) Cafeterias, grill buffets, and buffets
(21) Department stores
(22) Automotive parts and accessories stores
(23) Tire dealers
(24) Pharmacies and drug stores
(25) Credit unions

APPENDIX E

Tool VBA Code

E.1 Safety

```vba
Option Explicit

'==== SAFETY =====
'The code below was taken from TOPS-BC v1.2
Public Function accidentRate(vc As Double, accidentType As String, facilityType As String, vehicleType As String) As Double

Dim k As Long
Dim index As Long, lastIndex As Long
Dim cr As Range

accidentRate = 0# '# double

index = 0

Set cr = ActiveWorkbook.Names("crashRates").RefersToRange

For k = 1 To cr.Rows.Count

 If facilityType = cr.Cells(k, 1) Then
 index = k
 Exit For
 End If

Next k

If 0 = index Then
 Exit Function
End If

For k = index To cr.Rows.Count

 If accidentType = cr.Cells(k, 2) Then
 index = k
 Exit For
 End If

Next k

If 0 = index Then
 Exit Function
End If

For k = index To cr.Rows.Count

 If vehicleType = cr.Cells(k, 3) Then
 index = k
 Exit For
 End If

Next k

Dim maxIndex As Long

maxIndex = index + 1
Do While IsEmpty(cr.Cells(maxIndex, 3)) And maxIndex + 1 < cr.Rows.Count And IsEmpty(cr.Cells(maxIndex, 1))
 maxIndex = maxIndex + 1
```

```
Loop

maxIndex = maxIndex - 1

If vc > cr.Cells(maxIndex, 4) Then
 accidentRate = cr.Cells(maxIndex, 5) + _
 (vc - cr.Cells(maxIndex, 4)) * (cr.Cells(maxIndex, 5) - cr.Cells(maxIndex - 1, 5)) / _
 (cr.Cells(maxIndex, 4) - cr.Cells(maxIndex - 1, 4))
 Exit Function
End If

Do While vc > cr.Cells(index + 1, 4) And IsEmpty(cr.Cells(index + 1, 3)) And index + 1 < cr.Rows.Count And IsEmpty(cr.Cells(index + 1, 1))
 index = index + 1
Loop

If Not IsEmpty(cr.Cells(index + 1, 3)) Or index + 1 > cr.Rows.Count Then
 accidentRate = cr.Cells(index, 5)
 Exit Function
End If

If index = maxIndex Then
 accidentRate = cr.Cells(index, 5)
 Exit Function
End If

accidentRate = cr.Cells(index, 5) + _
 (vc - cr.Cells(index, 4)) * (cr.Cells(index + 1, 5) - cr.Cells(index, 5)) / _
 (cr.Cells(index + 1, 4) - cr.Cells(index, 4))

End Function
```

E.2 Speed

```
Option Explicit
'==== SPEED =====
'The code below was taken from TOPS-BC v1.2
Public Function speedFromVC(vc As Double, speedCurve As Range) As Double

Dim k As Long
Dim index As Long

speedFromVC = 0#

If vc <= speedCurve.Cells(1, 3) Then
 speedFromVC = speedCurve.Cells(1, 4)
 Exit Function
End If

index = 0

For k = 2 To speedCurve.Rows.Count

 If vc >= speedCurve.Cells(k - 1, 3).Value And vc <= speedCurve.Cells(k, 3).Value Then
 index = k - 1
 Exit For
 End If

 If Not IsEmpty(speedCurve.Cells(k, 1)) Then
 index = k - 1
```

```
 Exit For
 End If

Next k

If index = 0 Then
 If vc < speedCurve.Cells(1, 3) Then
 speedFromVC = speedCurve.Cells(1, 4)
 Else
 Dim maxIndex As Long
 maxIndex = 0
 For k = 2 To speedCurve.Rows.Count
 If Not IsEmpty(speedCurve.Cells(k, 1)) Then
 maxIndex = k - 1
 Exit For
 End If
 Next k
 speedFromVC = speedCurve.Cells(maxIndex, 4)
 End If
Else
 speedFromVC = speedCurve.Cells(index, 4) + _
 (vc - speedCurve.Cells(index, 3)) * (speedCurve.Cells(index + 1, 4) - speedCurve.Cells(index, 4)) / _
 (speedCurve.Cells(index + 1, 3) - speedCurve.Cells(index, 3))
End If

End Function
```

E.3 Travel Time Reliability

```
Option Explicit
'==== TRAVEL TIME RELIABILITY =====
'The code below was taken from TOPS-BC v1.2

Public Function ttrDelayRate(duration As Long, vc As Double, values As Range, lanes As Long) As Double

Dim k As Long
Dim index As Long

ttrDelayRate = 0#

If lanes < 2 Then
 Exit Function
End If

If vc = 0# Then
 Exit Function
End If

If lanes > 4 Then
 lanes = 4
End If

index = 0

For k = 2 To values.Rows.Count

 If vc >= values.Cells(k - 1, 2) And vc <= values.Cells(k, 2) Then
 index = k - 1
 Exit For
 End If
```

```

 If Not IsEmpty(values.Cells(k, 1)) And Not values.Cells(k, 1) = duration Then
 index = k - 1
 Exit For
 End If

Next k

If index = 0 Then
 If vc < values.Cells(1, 2) Then
 ttrDelayRate = values.Cells(1, lanes + 1)
 Else
 Dim maxIndex As Long
 maxIndex = 0
 For k = 2 To values.Rows.Count
 If Not IsEmpty(values.Cells(k, 1)) And Not values.Cells(k, 1) = duration Then
 maxIndex = k - 1
 Exit For
 End If
 Next k
 ttrDelayRate = values.Cells(maxIndex, lanes + 1)
 End If
Else
 ttrDelayRate = values.Cells(index, lanes + 1) + _
 (vc - values.Cells(index, 2)) * (values.Cells(index + 1, lanes + 1) - values.Cells(index, lanes + 1)) / _
 (values.Cells(index + 1, 2) - values.Cells(index, 2))
End If

End Function
```

E.4 Utilities

```
Option Explicit

'==== UTILITIES =====
'The code below was taken from TOPS-BC v1.2



Public Function FirstNonZero(one As Double, two As Double) As Double
If one = 0# Then
 FirstNonZero = two
Else
 FirstNonZero = one
End If
End Function


Public Function FirstNonEmpty(one As Range, two As Range) As Double
If IsEmpty(one) Then
 FirstNonEmpty = two.Value
Else
 FirstNonEmpty = one.Value
End If
End Function


Public Function Override(one As Range, two As Double) As Double
If IsEmpty(one) Then
```

```
 Override = two
Else
 Override = one.Value
End If
End Function
```

E.5 Help Window

```
Option Explicit
'==============================================================================================
==================
'== The code below shows the "help" window when the help button "?" is clicked ==
'It uses the form called "help_form" located in the form menu. The content is taken from
the cells in the worksheet "Help" tab
'The code updates the title.caption and the body.caption based on the name of the cell (e.g.,"HelpAverageDollarPurchas
e")
'This process is repeated for each help button.

Private Sub Average_Daily_Trips_Click()
help_form.help_title.caption = Worksheets("Help_Tab").Range("HelpDescAverageDollarPurchase").Value
help_form.help_body.caption = Worksheets("Help_Tab").Range("HelpDescAverageDollarPurchase").Value

help_form.caption = "Current Year - Help"
help_form.Show
End Sub

Private Sub Average_Purchase_Dollars_Click()
help_form.help_title.caption = Worksheets("Help_Tab").Range("HelpAverageDollarPurchase").Value
help_form.help_body.caption = Worksheets("Help_Tab").Range("HelpDescAverageDollarPurchase").Value

help_form.caption = "Current Year - Help"
help_form.Show
End Sub

Private Sub Current_Year_Click()
help_form.help_title.caption = Worksheets("Help_Tab").Range("HelpCurrentYear").Value
help_form.help_body.caption = Worksheets("Help_Tab").Range("HelpDescCurrentYear").Value

help_form.caption = "Current Year - Help"
help_form.Show
End Sub
```

The code is similar for all other “help buttons” in each worksheet.

E.6 Future Benefits

```
'===========================================================================================
=====================
'== the code below calculates the business cost savings for the “end year” of the period of analysis ==
'The code stores the values corresponding to
the initial year and runs the tool for the “future year” traffic. Once it gets the future savings,
it restores the initial year values.
'The code is executed by clicking the button "Calculate Fut. Savings" or after the "lost focus" event in the input cel
l for the "Average Traffic Growth (%)"


Private Sub future_benefits_Click()

```

```
Dim initial_volume As Double
Dim future_volume As Double
Dim traffic_growth As Double
Dim period As Double

Dim FutureBenefitsAuto As Double
Dim FutureBenefitsTruck As Double

'Store initial volume
initial_volume = ActiveSheet.Range("inputLinkVolume").Value

'Calculate future volume
traffic_growth = Worksheets("Parameters").Range("parameterTrafficGrowth").Value
period = ActiveSheet.Range("AnalysisPeriod_AM").Value
future_volume = initial_volume * (1 + traffic_growth / 100) ^ (period) 'Tf=(T0)*(1+g/100)^(years)


'Replace the initial traffic volume by future traffic volume (i.e., end of period volume)
ActiveSheet.Range("inputLinkVolume").Value = future_volume

'Report the values of future savings
FutureBenefitsAuto = ActiveSheet.Range("BaseYearAutoBenefits").Value
FutureBenefitsTruck = ActiveSheet.Range("BaseYearTruckBenefits").Value

ActiveSheet.Range("FutureYearAutoBenefits").Value = FutureBenefitsAuto
ActiveSheet.Range("FutureYearTruckBenefits").Value = FutureBenefitsTruck

ActiveSheet.Range("H175").Value = FutureBenefitsAuto
'Restore initial values (i.e., initial traffic volume)
ActiveSheet.Range("inputLinkVolume").Value = initial_volume

'Show message box confirming values
MsgBox ("Future Volume: " & Round(future_volume, 2) & vbNewLine & " Auto B. : " _
& Round(FutureBenefitsAuto, 2) & vbNewLine & "Truck B. : " & Round(FutureBenefitsTruck, 2))

End Sub
```

```
Private Sub Button_Future_Benefits_LostFocus()
'executes "future_benefits_Click()" after a growth factor is entered in the input cell
Call future_benefits_Click

End Sub
```

APPENDIX F

Road Diets Case Search Tool Overview

The Road Diet (RD) tool aims to provide information about the expected impacts of different sub-strategies according to contextual conditions such as volume of vehicles, land use, and location of the project. It is based on a database of 64 case studies where the impacts on safety, speed, traffic diversion, changes in capacity, and economic impacts were taken from available literature. The database was built in Microsoft Excel and it uses Visual Basic for Applications (Vba) to generate queries based on the selected criteria. The tool works best on Windows 7 and above operating systems; it also works on Macintosh operating systems with slightly limited productivity. The results of the queries are a number of case studies with similar characteristics and their impacts according to available literature. Figure F.1 shows a screenshot of the tool and the forthcoming paragraphs explain each section of the tool.

Choosing the "RoadDiet_Impacts" tab after opening the excel file yields the window above. The tool can be divided into "Section 1" and "Section 2."

Section 1 (inputs section)

The inputs section has 4 drop down menus and one check box along with 2 buttons. The 4 drop down menus are:

1.1. Road Diet Category. This search criterion asks to input one of the following categories- 4-lane to 2-lane conversion, 4-lane to 3-lane conversion, 5-lane to 3-lane conversion, other and multiple.

1.2. Context Classification. This search criterion asks to input one of the following categories: suburban, suburban/rural, urban.

1.3. AADT (Average Annual Daily Traffic). This search criterion asks to input one of the following AADT range categories: below 10,000 vehicles per day, between 10,000 and 15,000 vehicles per day and between 15,000 and 25,000 vehicles per day.

1.4. Land Use. This search criterion asks to input the land use type of the project location from a list of six general categories: commercial, residential, recreational, mix, schools/university, governmental. There is also a check box provided to populate results which have a bus route along with any of the above 4 search criteria.

Note that for each of the 4 drop down menus, at most one input can be selected. A 'blank' option can also be selected for any of the drop down menus. Figure F.1 gives an example where only one input is selected in the AADT drop down menu and others are left blank.

Clicking on the "Search Case Studies" (Section 1.4) button will execute the query and populate all the Road Diet cases studies matching the selected inputs.

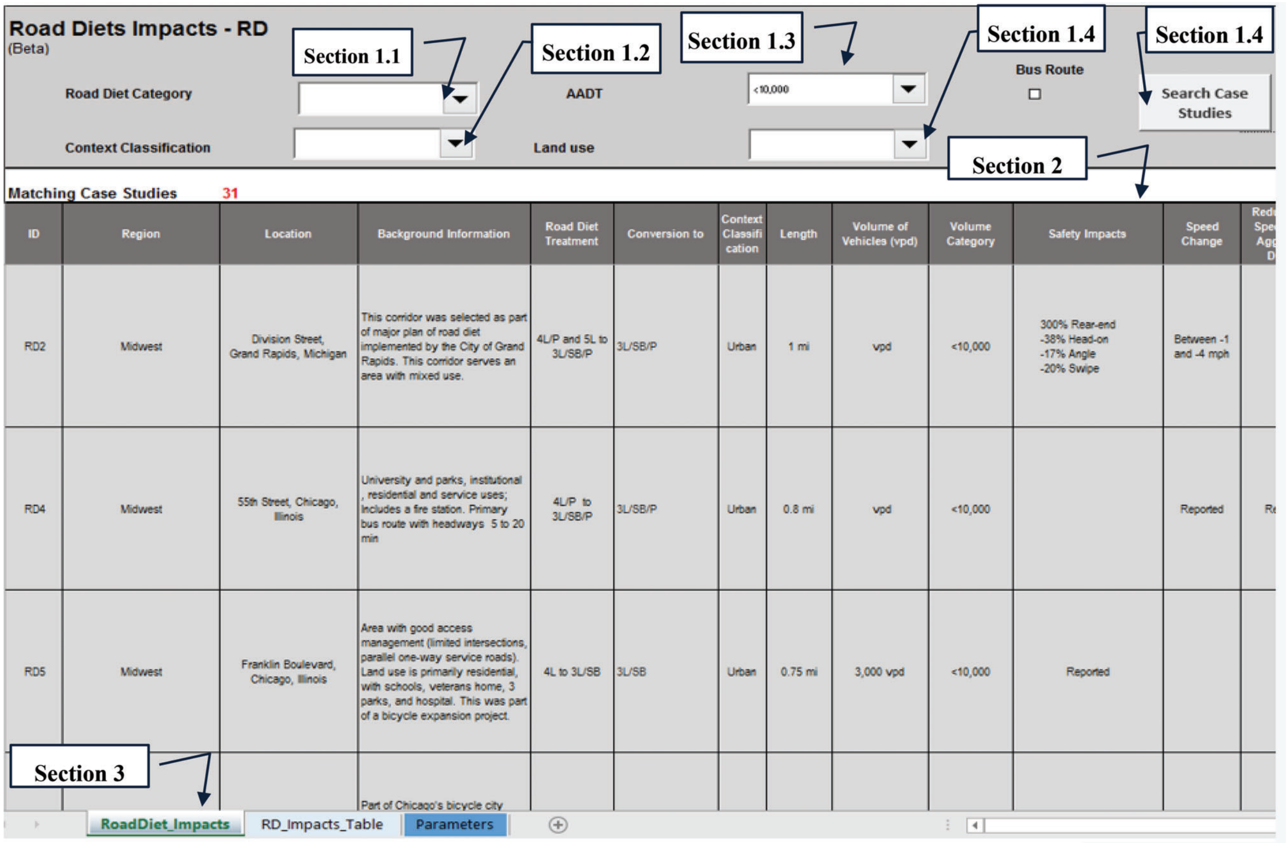
Clicking on the "Clear Results" button will clear all the case search results.

Section 2 (outputs section)

The outputs section populates results based on the inputs selected in the tool. The first row in this section indicates matching case studies—out of the 64 case studies that are stored in this search tool. All the matching case studies are listed below this row. A table with descriptions of each column heading is included in Appendix F.1. A table and two charts are included in Appendix F.2 to present the typology of case studies that can be retrieved with the tool.

Section 3 (tab navigation)

In addition to the "RoadDiet_Impacts" tab, the "RD_Impacts_Table" tab contains all the data gathered for the different Road Diets case studies. The "Parameters" tab has all the search criteria through which the tool searches.



Road Diets Impacts - RD
(Beta)

Road Diet Category
Context Classification
AADT <10,000
Land use
Bus Route ☐

Matching Case Studies 31

ID	Region	Location	Background Information	Road Diet Treatment	Conversion to	Context Classification	Length	Volume of Vehicles (vpd)	Volume Category	Safety Impacts	Speed Change	Redu Spe Agg D
RD2	Midwest	Division Street, Grand Rapids, Michigan	This corridor was selected as part of major plan of road diet implemented by the City of Grand Rapids. This corridor serves an area with mixed use.	4L/P and 5L to 3L/SB/P	3L/SB/P	Urban	1 mi	vpd	<10,000	300% Rear-end -38% Head-on -17% Angle -20% Swipe	Between -1 and -4 mph	
RD4	Midwest	55th Street, Chicago, Illinois	University and parks, institutional , residential and service uses; Includes a fire station. Primary bus route with headways 5 to 20 min	4L/P to 3L/SB/P	3L/SB/P	Urban	0.8 mi	vpd	<10,000		Reported	Re
RD5	Midwest	Franklin Boulevard, Chicago, Illinois	Area with good access management (limited intersections, parallel one-way service roads). Land use is primarily residential, with schools, veterans home, 3 parks, and hospital. This was part of a bicycle expansion project.	4L to 3L/SB	3L/SB	Urban	0.75 mi	3,000 vpd	<10,000	Reported		
			Part of Chicago's bicycle city									

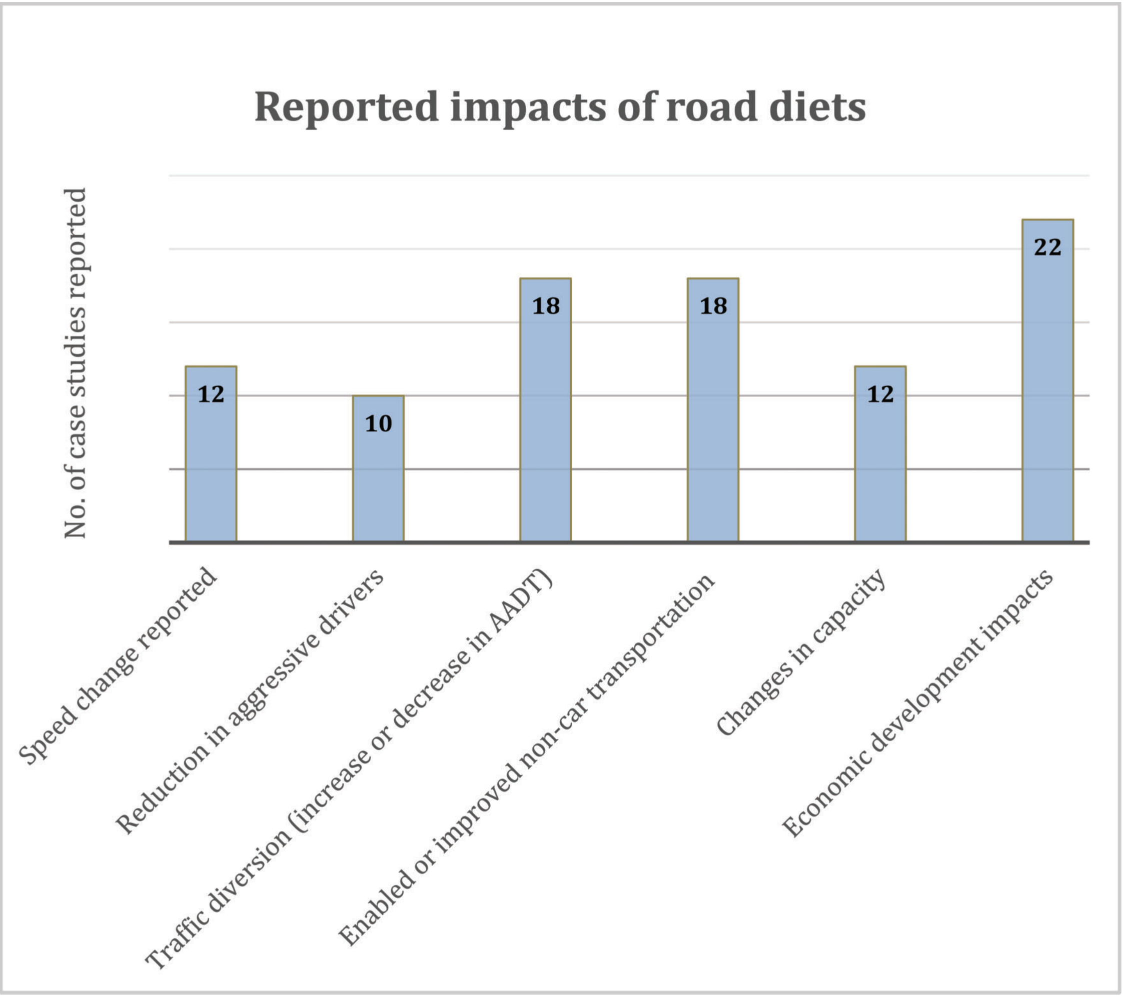
Figure F.1 Case search tool initial screen.

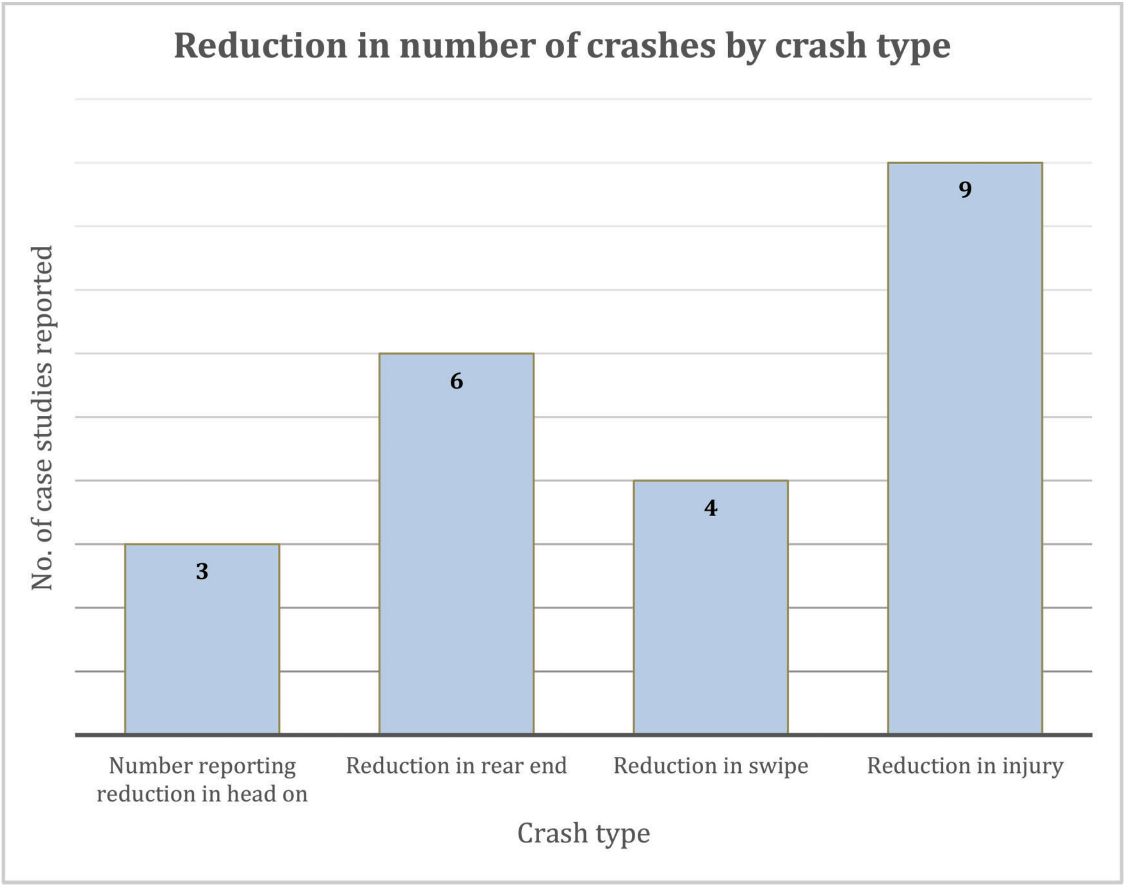
Appendix F.1 RD Tool Fields

Column Headings	Description
ID	ID number of the Road Diet case study (e.g., RD1)
Region	Region in the United States where the Road Diet was implemented (e.g., Midwest)
Location	Address where the Road Diet was implemented (e.g., Genesee County, Michigan)
Background Information	Brief description about the Road Diet project
Road Diet Treatment	Kind of Road Diet treatment used (e.g., 4L to 3L)
Conversion to	Number of lanes after the Road Diet treatment (e.g., 3L)
Context Classification	Land Use where the Road Diet was implemented (e.g., Urban)
Length	Length of Road in miles on which the Road Diet was implemented
Volume of Vehicles	Vehicles per day (e.g., 10000 vpd)
Volume Category	AADT volume category (e.g., 15000–25000)
Safety Impacts	Qualitative and quantitative safety impacts reported (e.g., % head on, % rear end)
Speed Change	Percent change in speed change and reported speed changes (e.g., between -1 and -4 mph)
Reduction in Speeders or Aggressive Drivers	Percent change or reported observations in number of speeders (e.g., 28%)
Traffic Diversion	Reported diversion in traffic in percent
Transit System	Whether a transit system was a part of the Road Diet (e.g., bus route)
Enabled or Improved Non-car transportation	Reported on surveys if the Road Diet improved non-car transportation
Changes in Capacity	Changes in the road's carrying capacity due to Road Diet treatment
Economic Development Impacts	Reported economic development due to Road Diets

Appendix F.2 Summary of Case Studies Considered in the RD Tool

Category	Land Use	No. of Case Studies	AADT	No. of Case Studies
4L to 3L	Commercial	26	<10000	2
	Residential	25	10000–15000	0
	Mix	0	15000–25000	3
	Recreational	4	No data	42
	School/university	5		
	Total	**47**	**Total**	**47**
4L to 2L	Commercial	2	<10000	2
	Residential	2	10000–15000	2
	Mix	0	15000–25000	0
	Recreational	0	No data	1
	School/university	1		
	Total	**5**	**Total**	**5**
Multiple	Commercial	No specific data	<10000	3
	Residential	No specific data	10000–15000	0
	Mix	No specific data	15000–25000	0
	Recreational	No specific data	No data	0
	School/university	No specific data		
	Total	**3**	**Total**	**3**
5L to 3 L	Commercial	2	<10000	1
	Residential	1	10000–15000	0
	Mix	0	15000–25000	2
	Recreational	0	No data	0
	School/university	0		
	Governmental	1		
	Total	**3**	**Total**	**3**


Reported impacts of road diets
No. of case studies reported
12
10
18
18
12
22
Speed change reported
Reduction in aggressive drivers
Traffic diversion (increase or decrease in AADT)
Enabled or improved non-car transportation
Changes in capacity
Economic development impacts


Reduction in number of crashes by crash type
No. of case studies reported
3
6
4
9
Number reporting reduction in head on
Reduction in rear end
Reduction in swipe
Reduction in injury
Crash type

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

About This Report

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